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LASER VIBRATION ANALYZER

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SUMMARY

This report describes a development program for the purpose of designing, fabricating, and testing a prototype laser vibration measuring instrument. During two previous study efforts, the optical heterodyne technique was selected as the most promising method for remote measurement of vibrations over a wide range of amplitudes and frequencies. The prototype instrument is designed to operate at a distance of three feet from the vibrating surface. The output beam is focused on the surface and can be scanned manually by means of a rotatable steering mirror. The output of the device is a frequency-modulated signal centered at 25 MHz; the phase shift of this signal is proportional to surface displacement. Vibration frequencies from 1 Hz to 0.5 MHz have been measured with this instrument, with displacements from 1/2 inch peak-to-peak down to approximately 10^{-4} microns. The surface may be specular or diffusely reflecting. This instrument is designed for use with a spectrum analyzer as the display device; however, means for operating the laser vibration analyzer with a tunable voltmeter or FM receiver for signal demodulation and recording are also described.

1. INTRODUCTION

This report describes work performed during the period from April 1967 through December 1967 and sponsored by the National Aeronautics and Space Administration, Ames Research Center. The purpose of this program was to develop a prototype laser vibration measuring instrument. During an initial study[1] in 1965 (Contract NAS2-3137), the general field of laser vibration experiments was investigated, and recommendations of the most promising techniques were formulated. In 1966 under Contract NAS2-3643 a breadboard demonstration of the optical heterodyne system was accomplished[2]. The test results with this breadboard were extremely favorable; hence this was the system selected for development up to the prototype stage under the present contract. The prototype instrument has important advantages as a vibration measuring tool, since it is non-contacting, has no mechanical resonances to limit the frequency response, and can be used to detect exceedingly small motions.

The basic specifications achieved during this development program are as follows:

a. The range of measurable vibration frequencies was to cover the range from 10 Hz to 2,000 Hz. The present prototype has been tested over the range from 1 Hz to 0.5 MHz with good results.

b. The dynamic range was to include vibration amplitudes from 1/2-inch to one micron peak-to-peak. The present instrument can be used over the 1/2-inch to 10^{-4} micron range when the vibrating surface is highly reflecting.

c. The above amplitude and frequency specifications were to be satisfied for specular surfaces of reflectivity greater than one percent or semi-specular, highly reflective surfaces such as unpolished machined surfaces. The present instrument satisfies the required specifications even with flat white surfaces returning less than 0.1% of the incident power to the instrument.

d. The instrument operates at distances over three feet from the surface, with a five-inch focusing range.

e. A 50-ohm output at 25 MHz for spectrum analyzer display is provided.

f. The size of the prototype instrument is approximately 2 by 3 feet with a height of 4 feet. The instrument is equipped with retractable wheels which allow the instrument to be moved about freely but do not interfere with the mechanical stability of the system during tests.

g. The unit is designed to operate in a normal laboratory environment from 115-volt, 60-Hz electrical power.

The output signal of the present instrument is designed for spectrum analyzer display. At large amplitudes of motion compared to the optical wavelength, the analyzer display is used to read peak-to-peak velocity of the surface directly. The amplitude of the motion is then calculable simply by dividing the velocity by the angular frequency of excitation. Conversely, the acceleration is found by multiplying the velocity by the angular frequency. For displacements smaller than a wavelength, the peak phase shift can be measured directly by comparing the relative heights of the sidebands to any table of Bessel functions. This quantity is proportional to displacement. The velocity and acceleration are then calculated by multiplying the displacement once or twice respectively by the angular frequency. The spectrum analyzer display has the advantage that bandwidth and gain can be adjusted to suit a particular measurement. However, it does limit testing to single frequency excitation because the test results otherwise become difficult to interpret and often ambiguous if comparable amounts of several frequencies are present simultaneously.

As indicated above, the instrument developed under this program generally exceeds the original specifications by a large margin. This is to a large extent due to the inherent sensitivity of the optical heterodyne technique, but it also is the result of using an extremely well-corrected optical system with photodetectors of high quantum efficiency and optimum rf coupling at the phototube outputs.

In Section 2 below the operating principles of the instrument are described. Section 3 deals with the design considerations involved in the engineering of the prototype. Performance data obtained in various tests of the system is given in Section 4. Procedures for operation and maintenance of the device are discussed in Appendix A of this report.

2. OPERATING PRINCIPLES

This instrument uses an optical heterodyne receiver to measure the phase shifts produced on a laser beam by reflection from a vibrating surface. In this scheme the laser output beam is divided into two parts. One part is transmitted to the vibrating surface through the optical system of the instrument. The other is shifted in frequency by an amount (in the present experiments approximately 25 MHz) large compared to the expected Doppler shifts on the reflected light from the surface under measurement. The shifted beam is sent to a beamsplitter mirror and from there directly into the photodetector; this beam is known as the reference or local oscillator beam. Some of the reflected light from the moving surface returns through the instrument optical system and is combined with the reference beam at the beamsplitter. A block diagram of this system is shown in Figure 1. Interference between the reference and signal beams is thus produced on the photodetector. A stationary surface produces interference which varies sinusoidally at the difference frequency, which is just equal to the shift or system intermediate frequency (IF). If the surface moves, the phase or frequency of the interference changes, producing frequency modulation of the system IF. The shift provides a frequency "bias" so that motions toward or away from the instrument produce distinctive Doppler modulations which give the motion direction as well as magnitude. The processing of the electronic signal from the detector is therefore relatively straight-forward. An analysis of the heterodyne detection process is given in the final report for Contract NAS2-3643; only the results are summarized here.

When the local oscillator and reflected signal beams are properly aligned and superimposed on a photodetector, the output current is of the form:

$$i(t) = I_{LO} + I_S + 2\sqrt{I_{LO}I_S}\ \cos\left[\omega t + \phi_S - \phi_{LO}\right] \qquad (1)$$

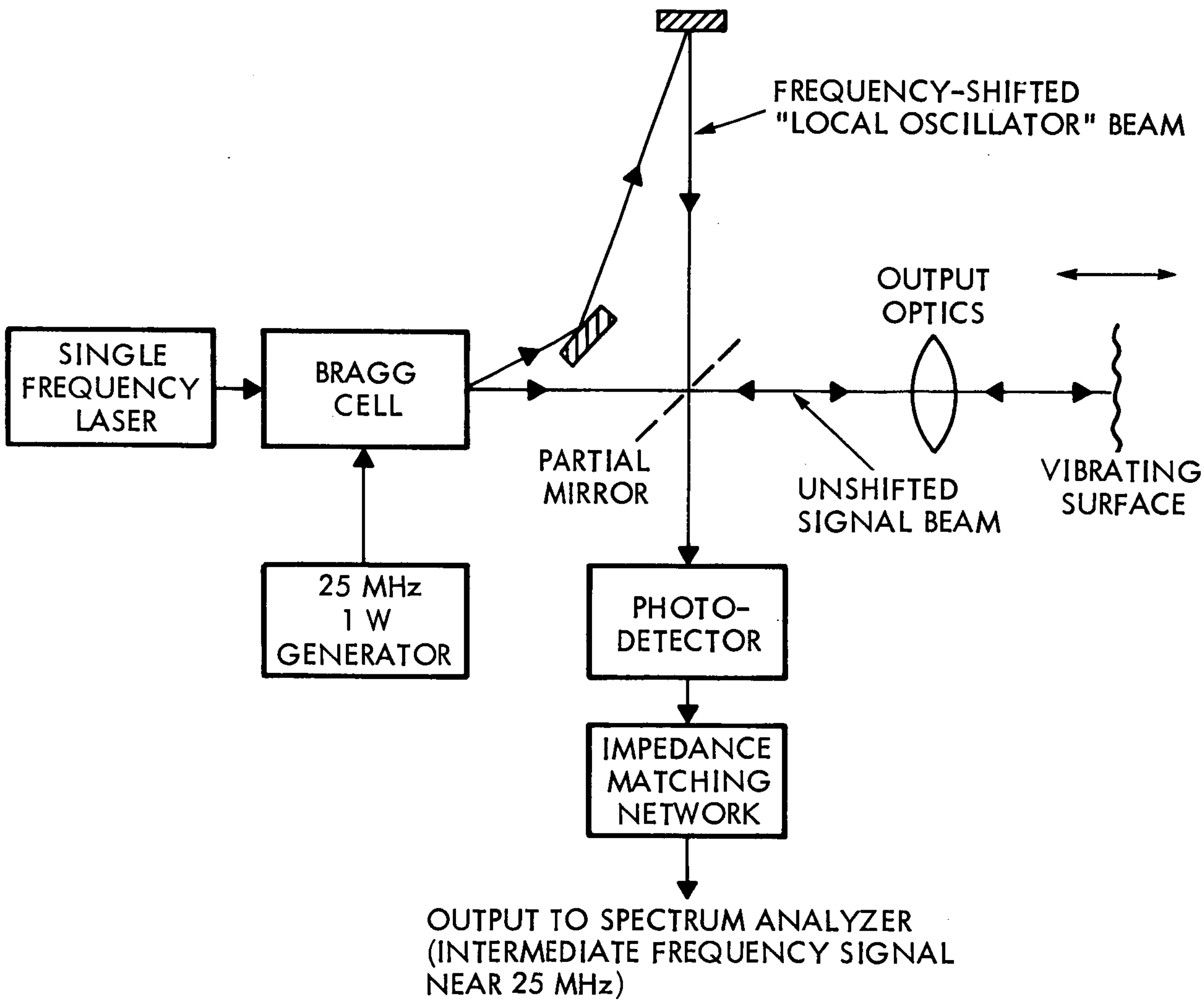

Figure 1. Block Diagram, Optical Heterodyne System.

where I_{LO} and I_S are the dc currents produced by the local oscillator and signal beams alone, and the interference term has a frequency ω equal to the shift frequency or system IF produced by the Bragg diffraction cell. The local oscillator phase is constant, depending only on the arbitrary choice of time reference; hence it can be set equal to zero. The signal phase ϕ_S varies with time such that for a sinusoidal vibration:

$$\phi_S = \frac{4\pi x_o}{\lambda} \sin \omega_v t \quad , \tag{2}$$

where x_o is the peak vibration amplitude, ω_v is the vibration frequency, and λ is the laser wavelength. This can be interpreted also as a frequency modulation by taking the time derivative of the phase:

$$\Delta\omega(t) = \frac{d\phi_S}{dt} = \frac{4\pi x_o \omega_v}{\lambda} \cos \omega_v t \quad \text{(radians per second)} \tag{3}$$

or

$$\Delta f(t) = \frac{1}{2\pi} \Delta\omega(t) = \frac{2x_o \omega_v}{\lambda} \cos \omega_v t \quad \text{(cycles per second)} \tag{4}$$

Therefore the ac component of the photodetector current is given by:

$$i_{ac} = 2\sqrt{I_{LO} I_S} \cos\left[\omega t + \frac{4\pi x_o}{\lambda} \sin \omega_v t\right] \tag{5}$$

This signal has an FM spectrum and can be expanded into an infinite series of Bessel function sidebands:

$$\begin{aligned} i_{ac} = 2\sqrt{I_{LO} I_S} \Bigg[& J_o\left(\frac{4\pi x_o}{\lambda}\right) \cos \omega t \\ & + J_1\left(\frac{4\pi x_o}{\lambda}\right) \cos (\omega + \omega_v)t \\ & - J_1\left(\frac{4\pi x_o}{\lambda}\right) \cos (\omega - \omega_v)t \end{aligned}$$

$$+ J_2\left(\frac{4\pi x_o}{\lambda}\right) \cos\ (\omega + 2\omega_v)t$$

$$- J_2\left(\frac{4\pi x_o}{\lambda}\right) \cos\ (\omega - 2\omega_v)t$$

$$\left. + \text{ higher order sidebands}\right] . \qquad (6)$$

For large vibration amplitudes x_o, and for low vibration frequencies ω_v, the set of sidebands approaches a continuum over the range $\omega \pm \frac{4\pi x_o \omega_v}{\lambda}$. The required angular frequency range over which the output coupling circuit must respond is therefore $\frac{8\pi x_o \omega_v}{\lambda}$. This "bandwidth" is determined then by the vibration characteristic product $x_o \omega_v$, and of course the laser wavelength λ. It has been assumed that this product $x_o \omega_v$ is a maximum at the lowest frequency of interest (10 Hz in this case); that is, we assume that the mechanical response x_o falls off with increasing frequency at least as fast as $1/\omega_v$ across the entire range of ω_v. This assumption is generally valid above the fundamental resonances of the structure. For the parameters in the prototype design and performance calculations, we have taken $(\omega_v)_{min}/2\pi = 10$ Hz, $(x_o)_{max} = 1/4$ inch, and $\lambda = 6328Å$; these values imply a frequency range of 2.5 MHz peak-to-peak at the phototube output.

For small vibrations we note that all the high order Bessel functions are small, and therefore it is sufficient to make the approximations:

$$J_o(\delta) \rightarrow 1 \qquad (7)$$

$$J_1(\delta) \rightarrow \frac{\delta}{2} \qquad \text{for small } \delta \qquad (8)$$

$$J_n(\delta) \rightarrow 0 \qquad (9)$$

for $n > 1$

Therefore the ac current for small x_o becomes:

$$i_{ac} \approx 2\sqrt{I_{LO} I_S} \left[(\cos \omega t) \pm \left(\frac{2\pi x_o}{\lambda}\right) \cos (\omega \pm \omega_v) t\right] \tag{10}$$

The information is now carried in the two-sideband frequency components of the current, which have peak amplitudes of

$$I_1 = 2\sqrt{I_{LO} I_S} \left(\frac{2\pi x_o}{\lambda}\right) \tag{11}$$

or r.m.s. amplitudes of

$$\frac{I_1}{\sqrt{2}} = \sqrt{2 I_{LO} I_S} \left(\frac{2\pi x_o}{\lambda}\right) \tag{12}$$

Essentially all of the returning light is used in producing the IF carrier component at ω. The detection process must not only recover the carrier, but must distinguish the sideband currents above the system noise in an instantaneous receiver bandwidth B. Using a relatively strong local oscillator beam and a sensitive multiplier phototube detector, the main noise contribution is from shot noise in the dc current produced by the local oscillator beam. This noise is given by:

$$i_n = \sqrt{2 \; e \; I_{LO} \; B} \qquad \text{(r.m.s.)} \tag{13}$$

where e is the electronic charge 1.6×10^{-19} coulombs.

The detection will therefore have a unit signal-to-noise ratio when the sideband current power is the same as the noise power in the circuit. Then:

$$S/N = \frac{2 \; I_{LO} \; I_S}{2 \; e \; I_{LO} \; B} \left(\frac{2\pi x_o}{\lambda}\right)^2 = \frac{I_S}{eB} \left(\frac{2\pi x_o}{\lambda}\right)^2 \tag{14}$$

or $$x_o = \frac{\lambda}{2\pi} \sqrt{\frac{e \; B(S/N)}{I_S}} \tag{15}$$

$$(x_o)_{min} = \frac{\lambda}{2\pi} \sqrt{\frac{eB}{I_S}} \; . \tag{16}$$

If we further note that a square-law detector of quantum efficiency η has the characteristic:

$$I_S = \frac{\eta \, e \, P_S}{h\nu} \tag{17}$$

where $h\nu$ is the energy of a photon of wavelength λ and P_S is the reflected optical power incident on the detector, we arrive at a final expression for small vibration sensitivity:

$$(x_o)_{min} = \frac{\lambda}{2\pi} \sqrt{\frac{h\nu B}{\eta \, P_S}} = \frac{1}{2\pi} \sqrt{\frac{hc\lambda B}{\eta \, P_S}} \tag{18}$$

In the present instrument operation with a fully reflective specular vibrating surface gives an equivalent $P_S = 10^{-5}$ watts with $\eta = 5 \times 10^{-2}$ (including losses in the narrow band filter) and $\lambda = 6328\text{Å}$. With a detection bandwidth of 10^4 Hz the theoretical value for $(x_o)_{min}$ is approximately 0.08Å. This is in good agreement with the measured instrument performance.

From the above results it is clear that motions very much larger or very much smaller than a wavelength of light can be measured equally well using a spectrum analyzer to display the output current spectrum. For motions with amplitudes of more than a wavelength, the total width of the spectrum

$$\Delta f = \frac{8\pi x_o f_v}{\lambda} \tag{19}$$

can be measured and x_o can then be calculated, since the wavelength λ is fixed and the vibration frequency f_v is selected by the person conducting the vibration test. For this case the double amplitude

$$2x_o = \frac{\lambda \, \Delta f}{4\pi \, f_v} \tag{20}$$

has been plotted over a reasonable range of values for f_v and Δf in Figure 2.

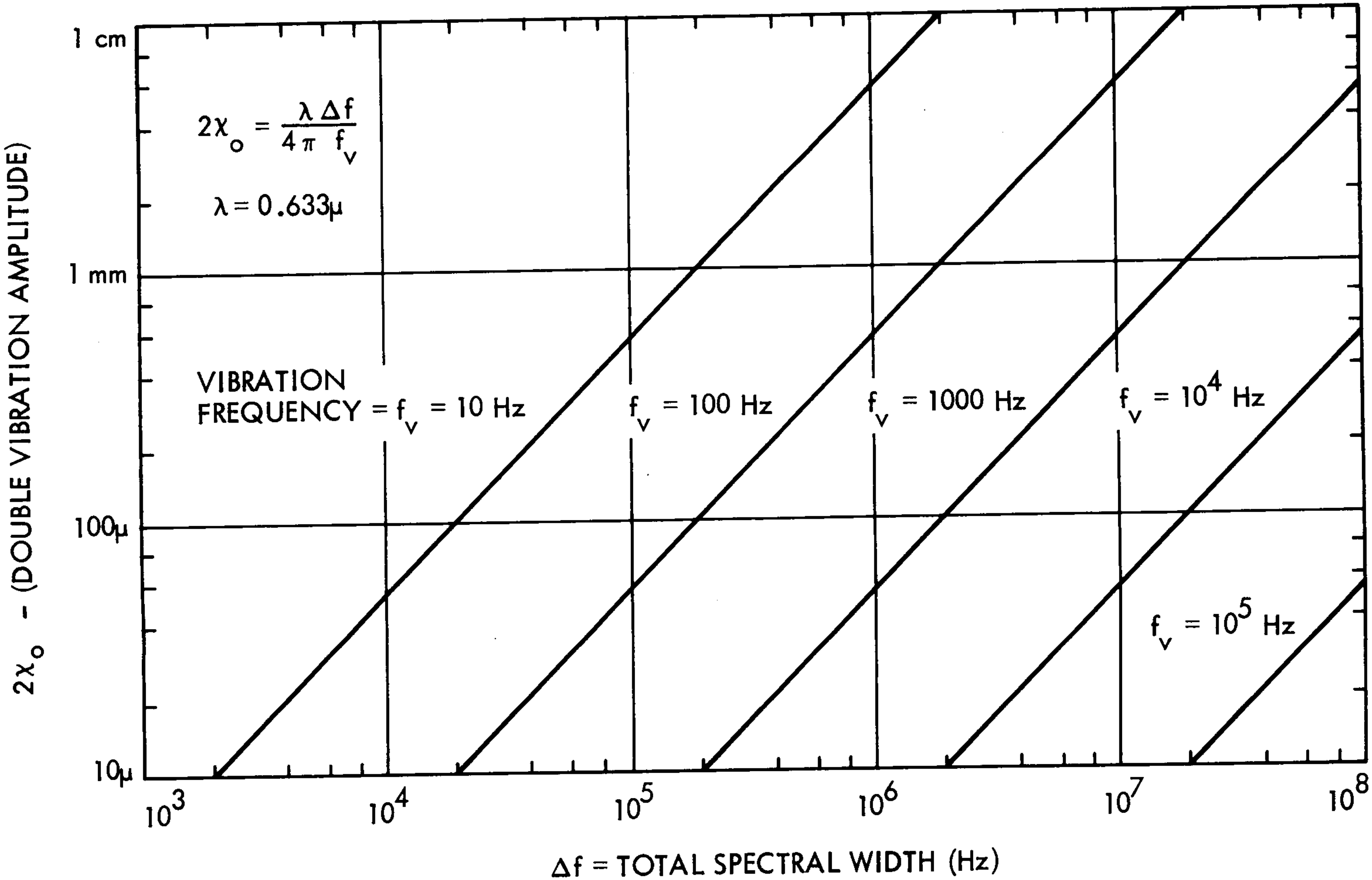

Figure 2. Vibration Amplitude Chart.

In the case of vibration amplitudes less than a few optical wavelengths, measurements of the amplitudes are made by a different procedure. Nearly all of the output signal is contained in the carrier, of relative amplitude $J_o\left(\frac{4\pi x_o}{\lambda}\right)$, and in the low order sidebands, whose amplitudes are given by $J_n\left(\frac{4\pi x_o}{\lambda}\right)$ as indicated in the Bessel function expansion given earlier. Usually the calculation is sufficiently accurate if the relative amplitudes of only two or three of the functions are compared. A convenient graphical tabulation of Bessel functions which is very useful in the interpretation of FM spectra in this range is given in Reference 2.

For motions less than one-tenth wavelength tables usually are unnecessary, since $J_o\left(\frac{4\pi x_o}{\lambda}\right)$ approaches one and $J_1\left(\frac{4\pi x_o}{\lambda}\right)$ approaches $\frac{2\pi x_o}{\lambda}$. Thus the ratio of the first sideband amplitude to the carrier amplitude gives $\frac{2\pi x_o}{\lambda}$ directly.

3. DESIGN CONSIDERATIONS

3.1 Operational Factors

The horizontal dimensions of the laser vibration analyzer were chosen as 2 feet by 3 feet at the beginning of the program. This choice was made because it represents the smallest size possible using the present type of optical system without substantial complication of the optical design for critical components. The height of the output beam was made approximately 40 inches so that test objects supported on ordinary work benches could be reached by the beam in a nearly horizontal direction. Controls were needed on the beam position so that it could be located accurately over an area approximately one foot square. Focusing over a depth of about five inches was also desired so that irregular surfaces could be tested without movement of the instrument location during the test. Wheels were required so that the instrument could be moved conveniently, and provision for retracting the wheels was needed so that the device would be rigidly mounted during tests. The electronic output signal was to be at 25 MHz, with frequency modulation suitable for display on a spectrum analyzer, at 50 ohms output impedance.

3.2 Optical System and Components

The basic optical system is shown in Figure 3. The system is drawn in one plane although the actual system is folded out of that plane by mirrors M_1, M_2, M_5, M_7, M_8, and M_9. Light from the laser is collimated to a beam about 3 mm in diameter by the lens L_1. This light interacts with a traveling 25 MHz sound wave in the Bragg cell to produce an unshifted beam, sent to the half-wave plate WP_1 , and a diffracted beam shifted in frequency by 25 MHz, sent to the 45° glass prism P_1. The diffracted beam is known as the local oscillator beam. In the present system approximately 1/6 of the light is diffracted into the local oscillator beam. This beam passes through the glass deflection block D, which is used for fine lateral alignment, to the beamsplitter mirror B. Reflected light from the beamsplitter reaches phototube (2) through the mirror M_9 and the narrow band interference filter F_2. The transmitted

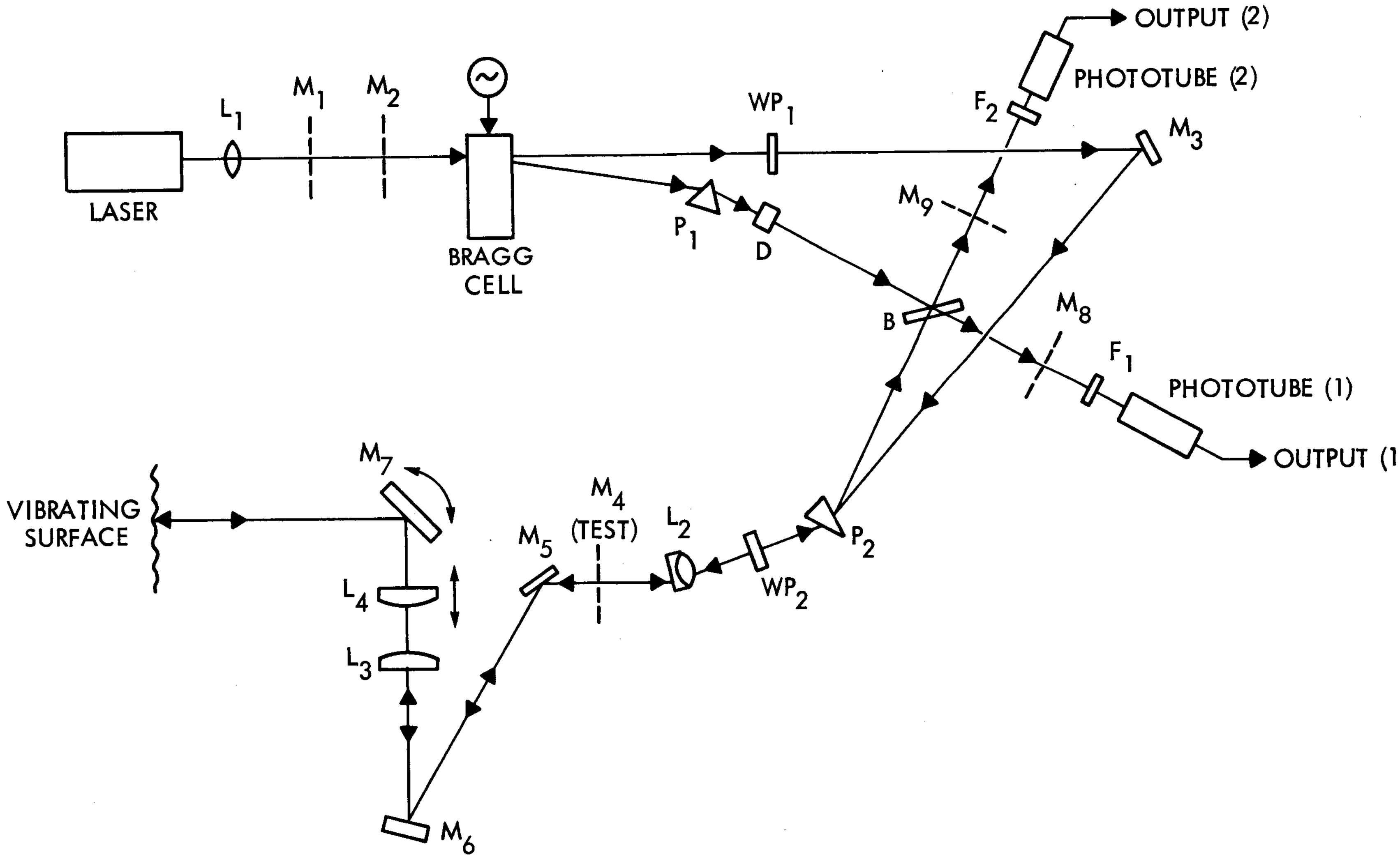

Figure 3. Laser Vibration Analyzer Optical System.

energy is sent to phototube (1) through a similar optical path.

The undiffracted beam leaving WP_1 is reflected by mirror M_3 to the 45° calcite prism P_2. The optic axis of the calcite crystal is normal to the plane of the paper in Figure 3. Prism P_2 and the quarter-wave plate WP_2 form an optical directional coupler which separates transmitted and received light passing through the relay optical system made up of lenses L_2, L_3, and L_4 and folding mirrors M_5 and M_6. The mirror M_7 is movable so that the output beam can be positioned at the desired location on the vibrating surface. There is also a movable mirror M_4 which is placed in the optical path only for alignment tests of the beamsplitter mirror and other components. It should be noted that the lens L_2 is a cemented doublet used off-axis to avoid any normal reflections which might reach the phototubes and interfere with the desired signal. All the air-to-glass surfaces are vacuum coated to reduce reflections to well below 1% per surface. The mirrors (except for M_4) are multilayer coated for the highest possible reflectance at 6328Å.

3.2.1 Laser

The 6328Å helium-neon laser* was selected as a source because it generates more than 100 microwatts of light at a single frequency, without spurious modulation which is ordinarily in multi-frequency lasers. The laser cavity is built into an oven, controlled by the laser power supply to maintain a fixed cavity length and output wavelength. The exact resonator length is adjustable piezoelectrically for maximum output by means of a potentiometer (the "Manual λ Control") on the laser power supply panel.

3.2.2 Bragg Diffraction Cell

This device, which produces the radio frequency shift on the local oscillator beam, makes use of the interaction of light and sound in water[(1)]. A plane traveling acoustic wave at 25 MHz is set up in the water by vibration of a quartz crystal 5 cm in diameter at one end of the cylindrical pyrex vessel containing the liquid. The thickness of the quartz is chosen so that it vibrates in resonance at the 5th overtone.

*Model 119, Spectra Physics, Inc., Mountain View, California.

The laser beam is introduced through windows in the sides of the vessel at an angle $\theta = \sin^{-1} \frac{\text{(optical wavelength)}}{2 \times \text{(acoustic wavelength)}}$. At this angle the incident and diffracted light waves remain in phase with the acoustic wave over the interaction volume, a condition necessary for the diffraction to be substantial. In the present geometry the diffracted light is Doppler-shifted upward in frequency by the scattering process, so that the diffracted wave has a frequency 25 MHz higher than the undiffracted light.

The vessel is constructed of pyrex glass and stainless steel to avoid corrosion. The matching network which couples the 50 ohm input connection to the crystal is mounted in the aluminum cylinder behind the crystal. Because the quartz crystal is fragile and faces the water on one side only, a pressure relief diaphragm is mounted in the black phenolic cap which seals the top of the vessel.

3.2.3 Relay Optical System

The lenses L_2 , L_3, and L_4, which make up the relay telescope, were fabricated to the following specifications*:

1. Operating wavelength - 6328Å.
2. Entrance Pupil Diameter - 3 millimeters, off-axis.
3. Exit Pupil Diameter - 75 millimeters nominal.
4. Focal length of large lenses (L_3 and L_4) - 48 inches.
5. Wavefront Distortion for Two Passes - less than 1/4 wave.
6. Field of View - 3 milliradians minimum.
7. Lenses to be mounted in black anodized cylindrical cells.

The design of the system is as follows. At the entrance pupil (L_2), the incident beam is 3 mm in diameter and approximately 3 mm offset from the lens axis. The lens L_2 is a highly corrected cemented doublet with a 1.788-inch back focal length. The index of the convex element is 1.52081 and that of the concave element is 1.71686. The lenses L_3 and L_4 are plano-convex singlets, used on-axis, with residual spherical

*Optical Instruments Corporation, Buena Park, California.

aberration removed by hand figuring of the plano surface. These lenses were made of BK-7 glass with refractive index 1.51476. The small mirror M_5 has a fused silica substrate and is flat to 1/20 wave. M_5 is identical to M_1, M_2, M_3, M_8, and M_9. The large mirrors M_6 and M_7 are pyrex, and were fabricated to a flatness of 1/10 wave*. Performance data obtained for the entire system indicates that the optical quality of the assembled relay telescope is excellent.

3.2.4 Multiplier Phototubes

Two multiplier phototubes** connected in the balanced mixer configuration are used in the system to achieve the best possible signal-to-noise ratio and spurious modulation suppression. The tubes used were a selected pair with S-20 photocathodes and ten dynode stages. The quantum efficiency of these tubes is slightly over 8%. The maximum output current is 1 milliampere; thus, it is necessary to use only six of the ten stages for gain. This is accomplished by shorting together electrodes no. 6 - 11 on the tube socket and using these as the anode or output connection, as shown in Figure 4. The polarity of the secondary turns on the resonant transformer was made opposite on the two tubes so that the output currents, which are already 180° out of phase because of energy conservation in the heterodyne process, could be added directly. Because of the parallel connection of both tubes into a 50-ohm line, the transformer secondary of each is 100 ohms. This method of connection tends to reject spurious amplitude modulation, which is produced in-phase in both tubes. A total of about 10 milliamperes of direct current at 1100 volts is needed to run both tube circuits. A precision gain balance is achieved by applying the high voltage through the wiper contact of a 50 kΩ potentiometer, with each of the tube circuits connected to one end of the potentiometer resistance. The position of the wiper is then set to balance the gains for both tubes.

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*Tinsley Laboratories, Berkeley, California.

**Type 7326, Radio Corporation of America, Harrison, New Jersey.

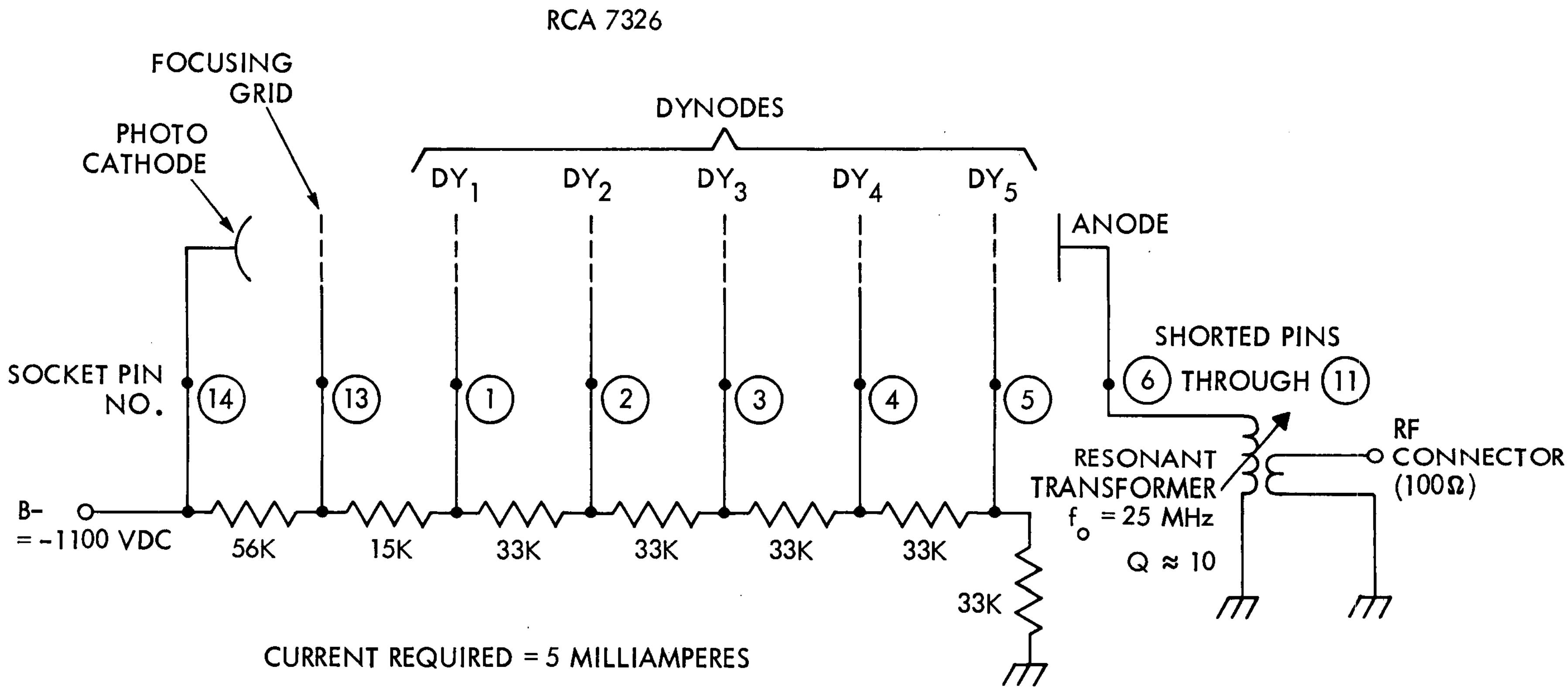

Figure 4. Multiplier Phototube Circuit Diagram.

The tubes are mounted in aluminum housings 4 inches square. In front of each photosurface is a light baffle to limit the field of view and a coated right angle prism which allows the light to be incident from the side of the housing. At the entrance hole on each housing is mounted a narrow band interference filter. This allows the operation of the vibration analyzer system with the optical deck cover removed and normal room lights on. These filters* have a spectral bandwidth of 37Å with peak transmission of 85% centered on 6328Å.

3.3 Mechanical Components

The mechanical portion of the system is divided structurally into a frame assembly, which carries the electronic components and wheel assembly, and an optical deck, which rests on the frame and holds the optical components precisely in position.

The structure of the frame is made of 2-inch aluminum angle stock, welded into a single unit. The wheel retracting system, consisting of four casters mounted on a crank-operated linkage which can be raised or lowered by hand, is bolted to the bottom of the aluminum frame. Baffles are mounted inside the frame to exclude dust and hot air generated by electronic components from the optical path. The electronic parts are rack-mounted into one end of the frame, and controls for the optical adjustments are located on the opposite end. The removable sheet metal sides are louvered to provide ventilation for the power supplies.

The optical deck is an aluminum casting 3/4 inch thick. The laser, collimating lens, phototube housings, and portions of the relay optical system are mounted below the surface of this casting; other components are mounted on top. Focusing is accomplished by moving the last lens in the system along a pair of ground steel ways by means of a right-angle gear drive system. Position of the beam is controlled by the motion of a 5-inch optically flat mirror mounted in a gimbal at the system output. The rotation axes are driven through compact speed-reducer gear systems with a ratio of 2500:1. Because of the low torque limits at the outputs of these speed-reducing units, an over-ride clutch is provided on the vertical

*Thin Film Products, Inc., Cambridge, Massachusetts.

control axis and a deformed O-ring friction drive is used on the horizontal control axis. The O-ring effectively decouples any interaction torques between the two axes. A nylon shear pin is also located on the horizontal control axis at the speed reducer output to avoid the possibility of damage to the gear system by accidental manual force applied to the mirror, should the instrument be operated with the cover removed.

The beamsplitter mirror orientation is the most sensitive adjustment in the system. This element is mounted on a fixture designed to resist misalignment due to vibration during transit. The fixture uses elastic deformation of the base itself, under pressure applied through fine-thread screws, to achieve accurate angular alignment of the beamsplitter in the vertical and horizontal planes. The deflector block is used to achieve translational alignment (overlap) of the two beams incident on the beamsplitter mirror.

A rotatable aluminimized mirror (M_4 in Figure 3) is mounted beyond the doublet lens (L_2) as an alignment fixture. In normal operation, the mirror is rotated 120^o from the vertical, so that it lies outside the optical path. To check the system alignment with the instrument cover removed, this mirror is rotated 120^o so that the fixture is vertical and centered on three supporting points. Light is then reflected back into the system as though a properly adjusted surface were located at the focus of the relay lens system. The 25 MHz signal thus produced at the system output can be used to align the beamsplitter mirror for maximum output. The correct magnitude of this signal also indicates proper functioning of the laser, Bragg cell, oscillator, and phototubes, after the alignment adjustments have been made.

The optical deck assembly is partially isolated from vibrations of the frame by a neoprene gasket below the deck surface and by small O-rings located under the mounting screws on the upper surface.

Figures 5 and 6 are diagrams of the mechanical and optical configuration used in the prototype instrument. Figure 7 is a photograph of the optical deck assembly with the cover removed, and Figure 8 shows the internal mounting of the components with the side panels removed. Figures 9 and 10 show the electrical and mechanical controls on the completely assembled instrument.

3.4 Electrical Components

The electrical system of the instrument consists of the laser power supply, phototube high voltage supply, oscillator driver for the Bragg cell, and low voltage supply for the oscillator.

The laser power supply performs two basic functions. It provides power for the discharge in the laser tube and also maintains a stable optical cavity length through thermal and piezoelectric controls in the laser head. The cavity length is held constant because it is mounted inside a thermostatically controlled oven. When the supply is set in either the "standby" or "on" positions, the oven is operating. The "standby" mode is provided so that the laser may be permanently connected to the power line and operated when desired without warm-up. If the unit is turned off, a three-hour warm-up is required before the laser cavity is stabilized. The piezoelectric manual "$\Delta\lambda$" control allows manual adjustment of the optical cavity over a few half wavelengths. This control is used in the present system for achieving maximum output power by tuning the laser oscillation frequency to an optimum portion of the atomic fluorescence line.

Details of the construction and maintenance of the laser and supply are given in the operating manual for the laser, which was delivered along with the instrument.

The phototube assemblies in the instrument require approximately -1100 volts at a direct current of about 5 milliamperes per tube. This is supplied by a dc high voltage source*. Although this unit is variable

*Model 1547, Power Designs, Inc., Palo Alto, California.

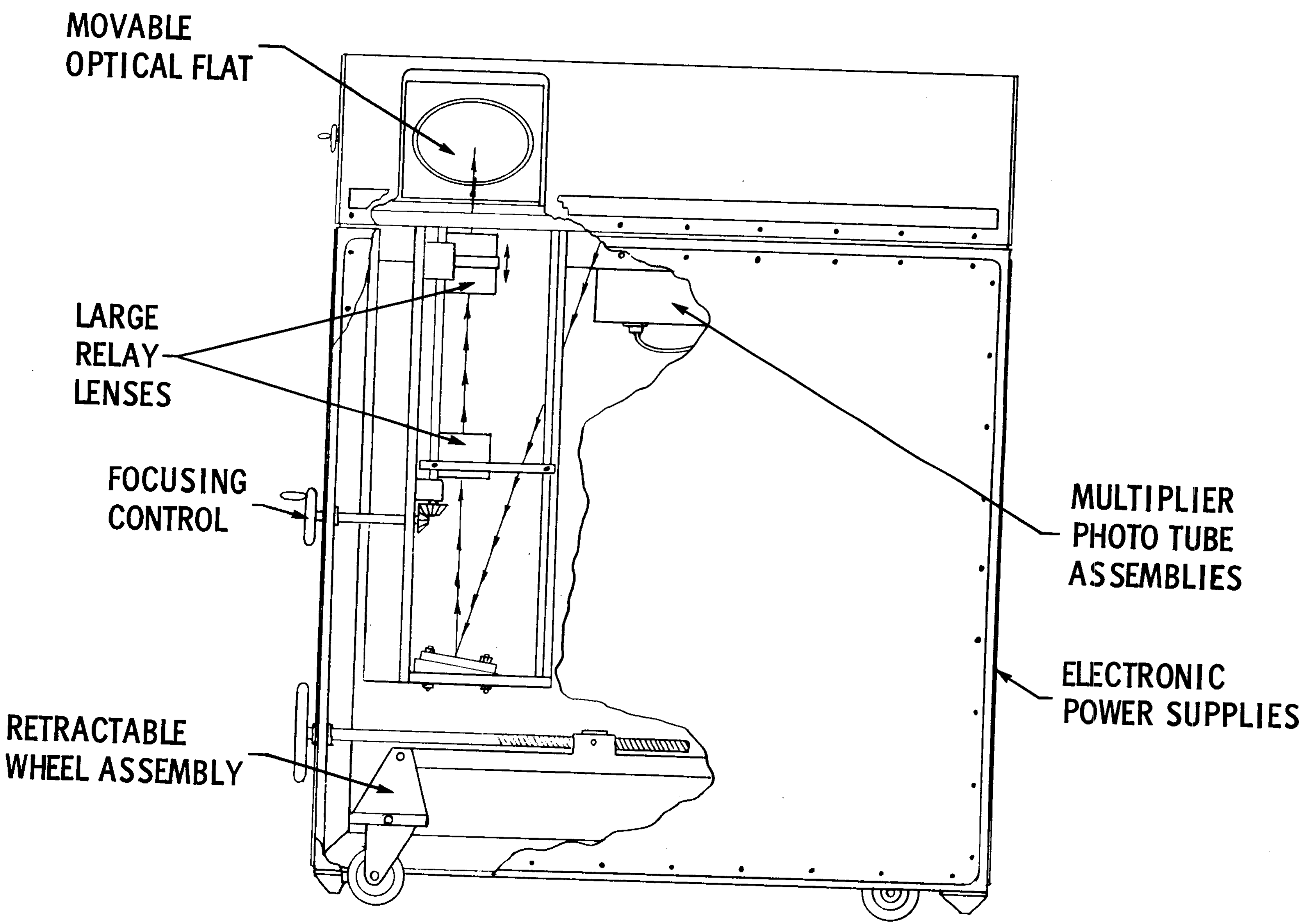

Figure 5. Vibration Analyzer Mechanical Configuration - Side View.

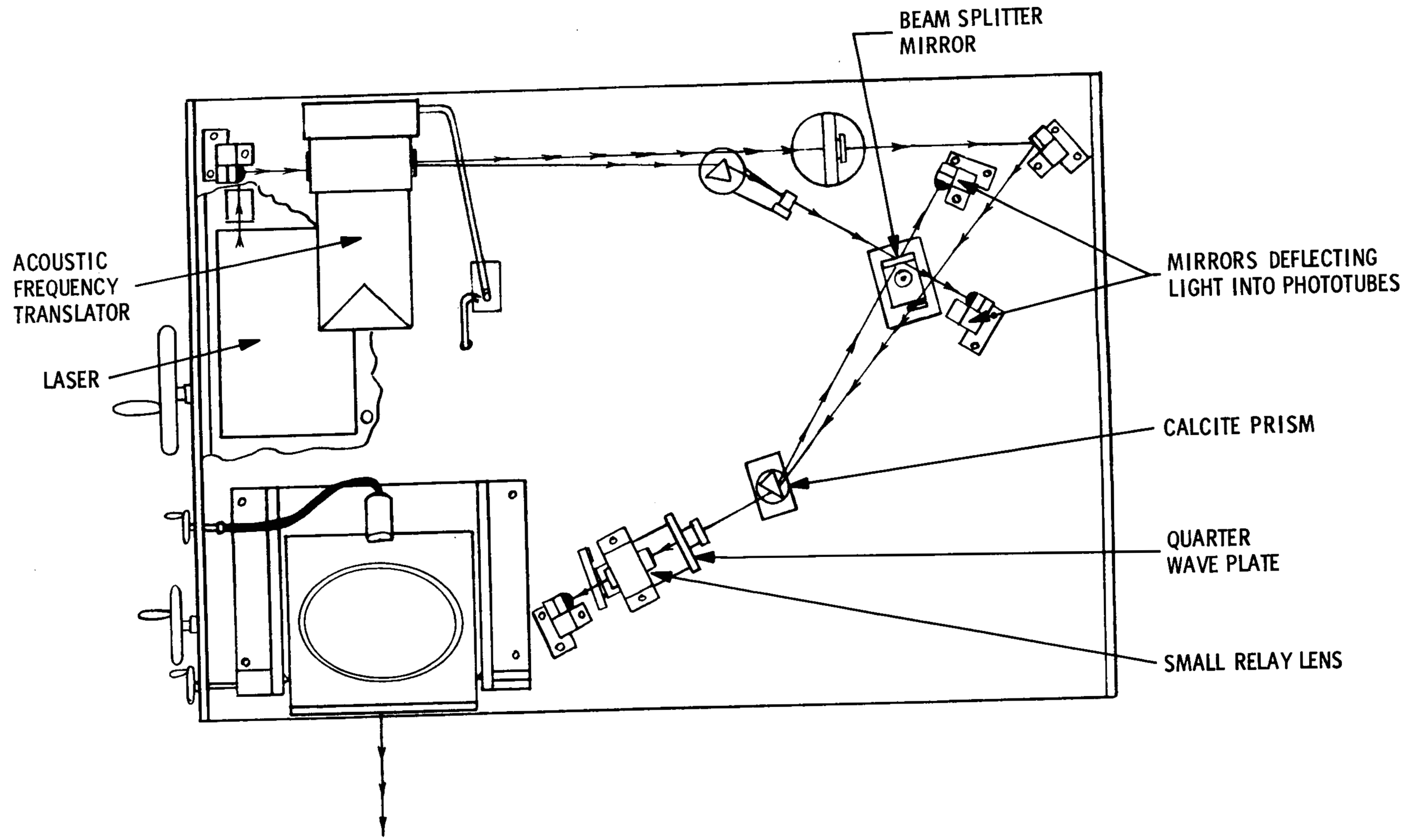

Figure 6. Vibration Analyzer Mechanical Configuration - Top View.

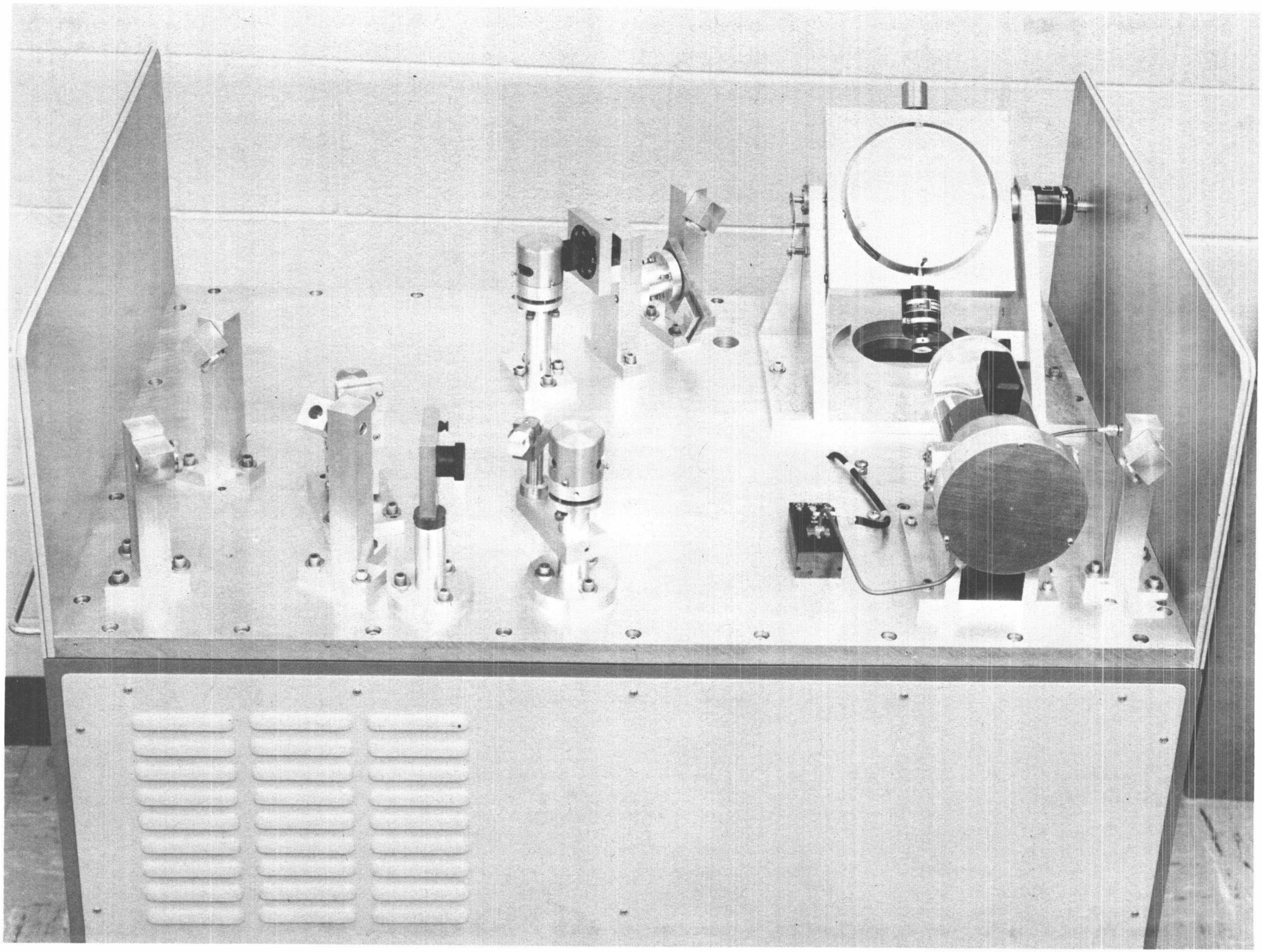

Figure 7. Photograph, Optical Deck.

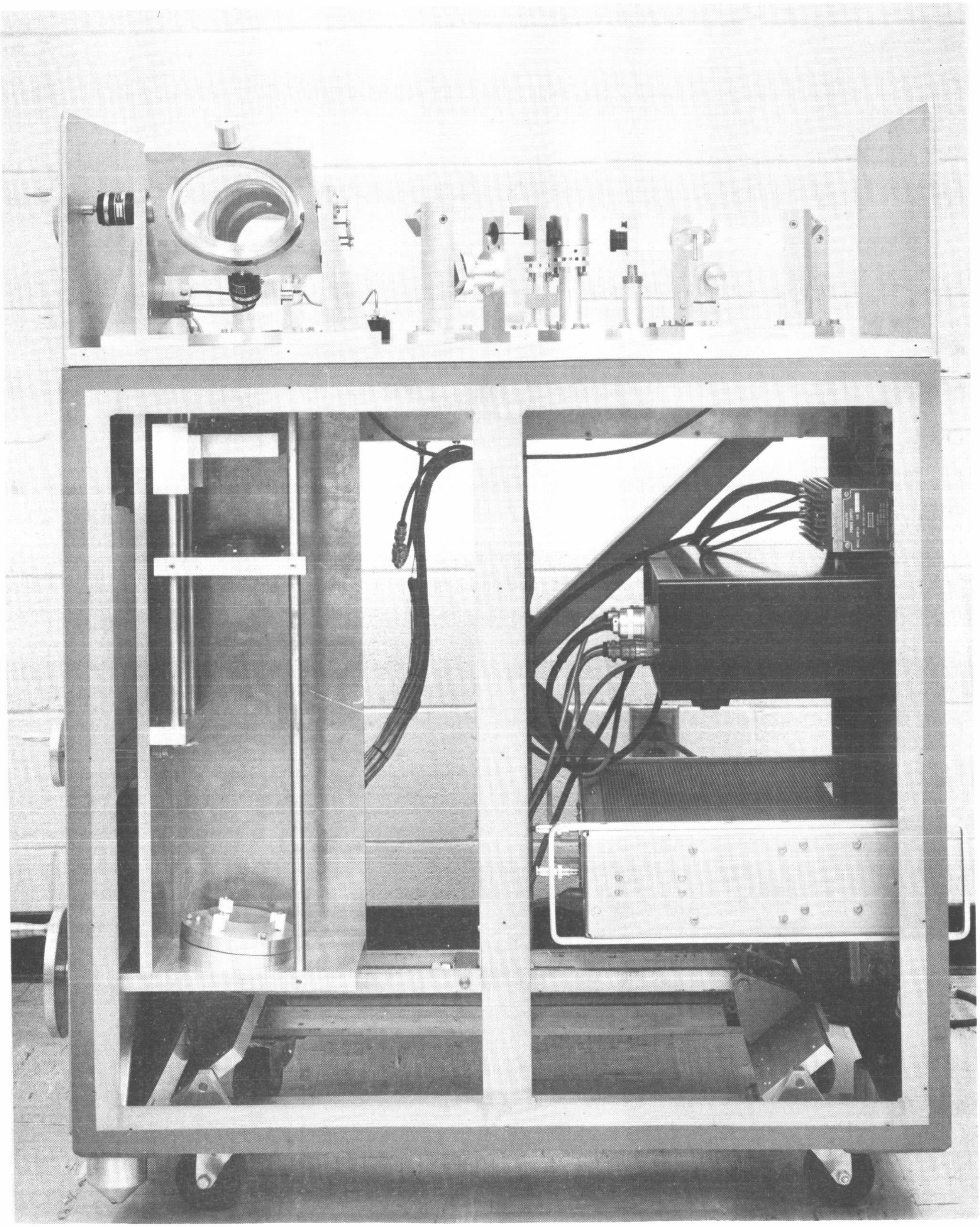

Figure 8. Photograph, Vibration Analyzer with Sides and Cover Removed.

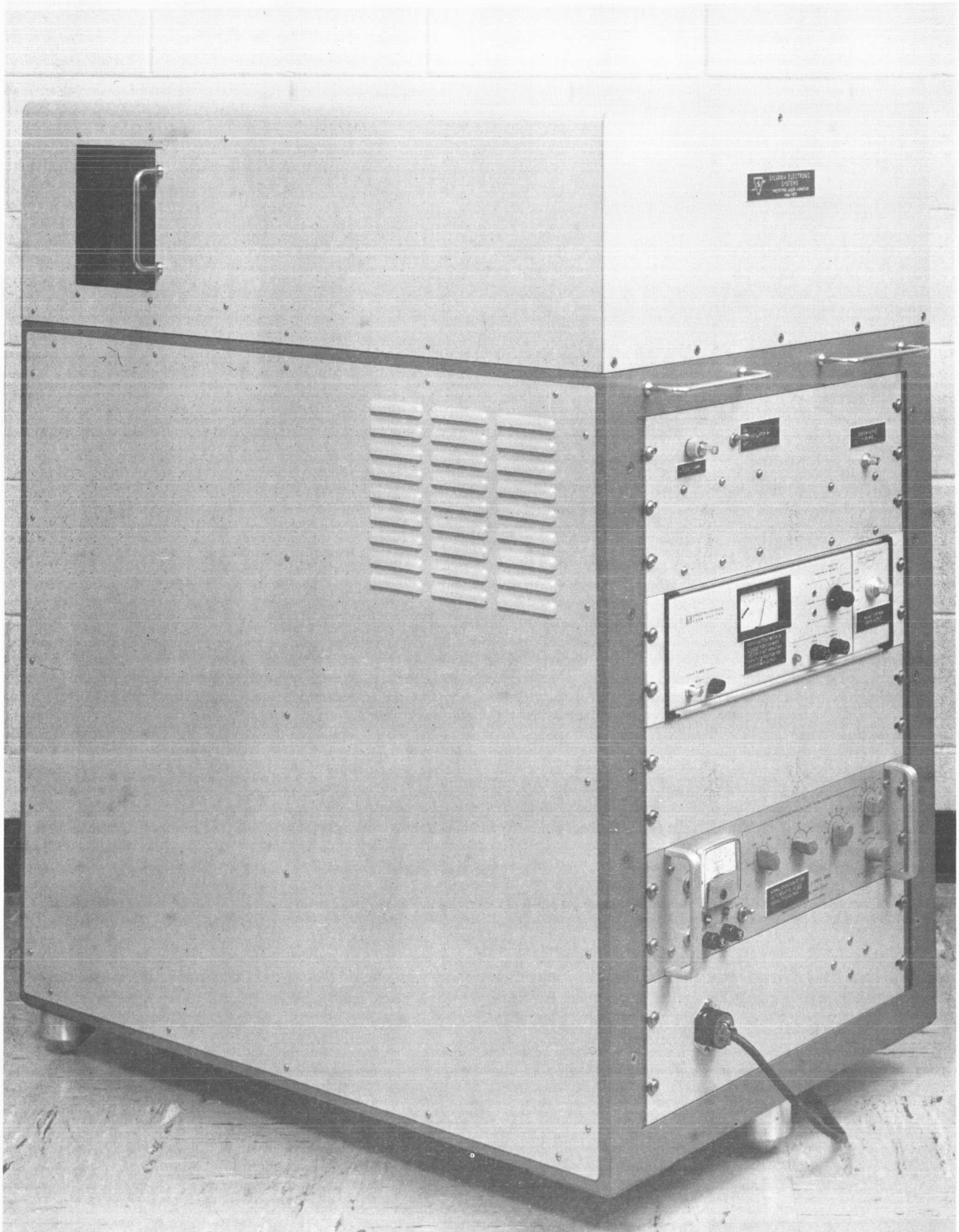

Figure 9. Photograph, Assembled Vibration Analyzer.

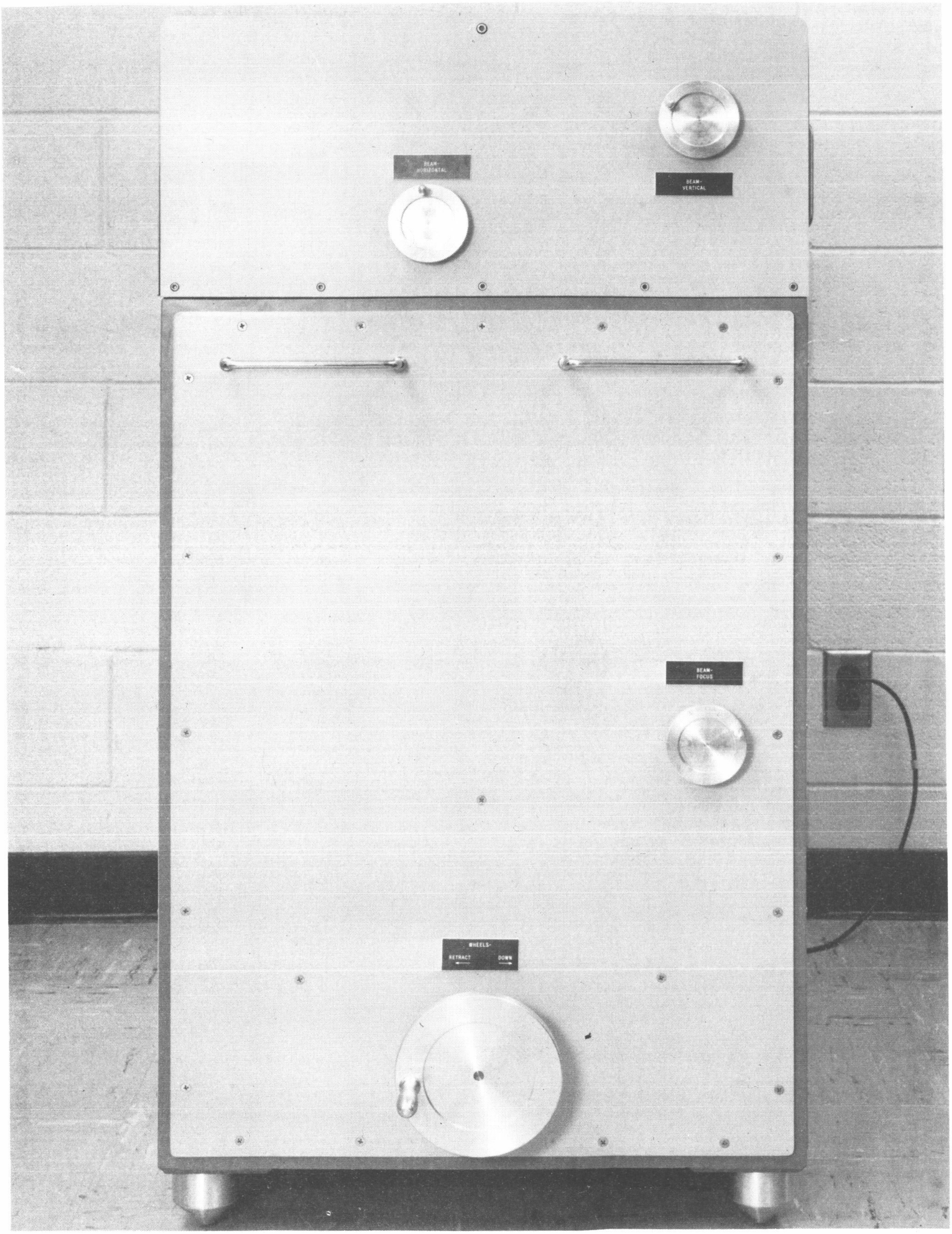

Figure 10. Photograph, Vibration Analyzer Mechanical Controls.

and can be set to provide more or less than the optimum 1100 volts negative, greater voltages will damage the phototubes and should not be applied. Lower voltages than the rated value will merely reduce gain in the tubes, ultimately reducing the signal-to-noise ratio. As mentioned in the earlier description of the phototube assemblies, the balance of gain is accomplished by a potentiometer mounted inside one of the tube assemblies; the external high voltage need not be adjusted in normal operation. Details of the performance, circuit diagrams, and maintenance instructions are included in power supply instruction manual provided with the instrument.

The oscillator driver* for the Bragg cell provides up to 2 watts of rf power at 25 MHz into a 50-ohm load. Power level and frequency adjustments on the oscillator have been set for optimum performance and should not be disturbed. This device uses the main casting of the optical deck as a heat sink. Specifications for the device are as follows:

1. Input power - 28 VDC at less than 255 ma.
2. Maximum output power - 2 watts (variable down to 20 mw).
3. Frequency - tunable 24 - 26 MHz. Stable to within 30 kHz from $0^{\circ}C$ to $60^{\circ}C$.
4. Harmonic distortion - all harmonics more than 22 dB down.

The oscillator is sensitive to VSWR and should not be operated except into the modulator (when tuned to the proper frequency) or into a 50-ohm load.

The 28-volts dc for the oscillator is supplied by a solid-state power supply**. This unit can provide up to 1 ampere at 28 volts, which is more than adequate for the present application. Details of the circuit are contained in the operating manual for this supply, also included in shipment with the instrument. Since the oscillator and its supply are completely solid-state circuits, no warm-up period is required for these components.

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*Western Microwave Laboratories, Inc., Santa Clara, California.

**Model UPM-44, Power Designs, Inc., Palo Alto, California.

An overall electrical wiring diagram for the system is given in Figure 11.

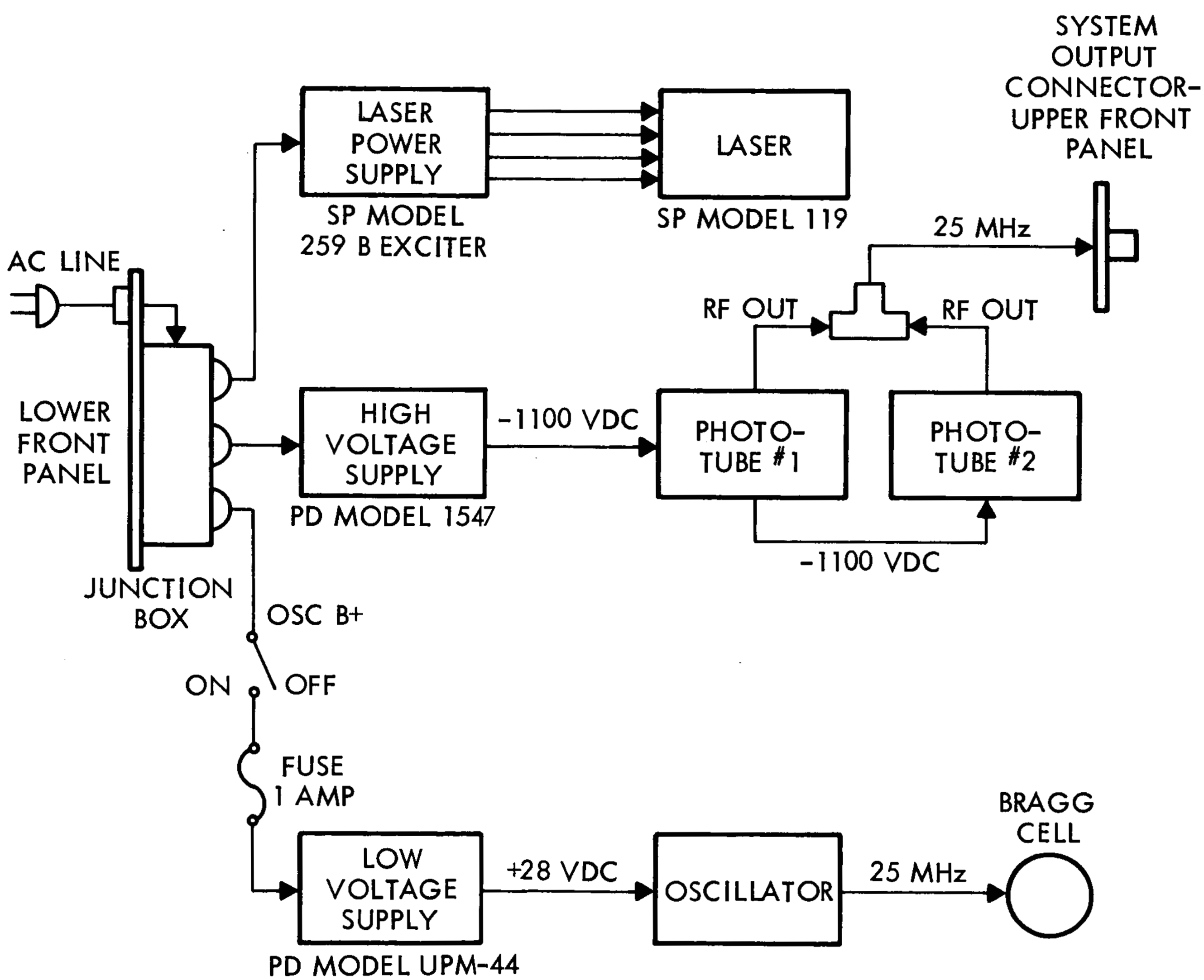


Figure 11. Block Diagram, Electrical System.

4. MEASURED PERFORMANCE AND EXPERIMENTAL DATA

The tests made to determine performance characteristics were in three principal categories:

1. Tests to determine large and small vibration amplitude sensitivities.

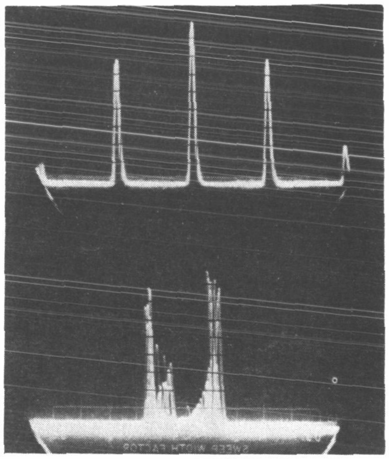
2. Tests to determine the heterodyne signal strength at the system output for several reflecting surface materials.

3. Tests to determine optical power levels and losses at various points in the optical system.

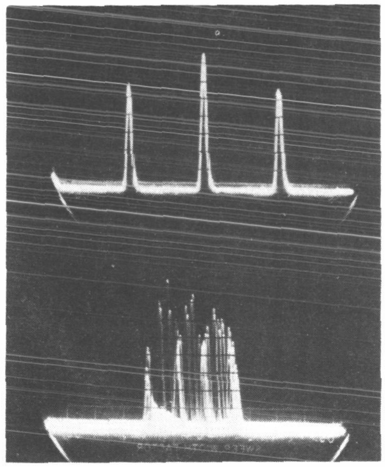
The results of the amplitude sensitivity tests are shown in Figures 12 and 13. In Figure 12 the response to large and medium amplitude excitations are shown. The 1/2-inch peak-to-peak displacement was obtained using a motor-driven reciprocating mirror at a speed corresponding roughly to 1 Hz. The others were taken using a mirror mounted on a loudspeaker voice coil. In each case the system response is the <u>lower</u> trace; the upper trace is a marker signal introduced to indicate beat frequency spread. Peak-to-peak displacement, vibration frequency, and marker spacing are indicated for each case.

Figure 13 shows some small amplitude spectra. Since the sidebands are resolved by the spectrum analyzer, no frequency marker is needed. Amplitudes and frequencies of the vibrations are given. The traces taken at 250 kHz and 570 kHz demonstrate the capability of this instrument for measuring mechanical vibrations at frequencies into the radio frequency band.

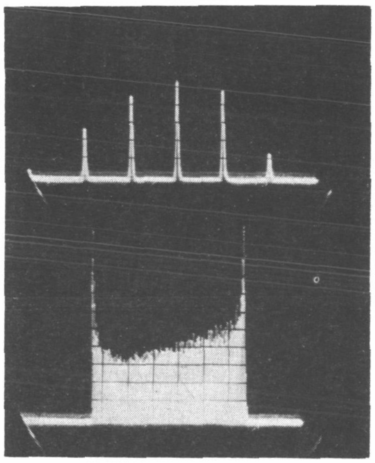
The heterodyne signal power was measured for a number of surfaces, some of which were test samples supplied by the Government technical monitor for this project. Measurements were made by adjusting the instrument focusing control for maximum signal on the spectrum analyzer and then substituting a known signal of the same strength obtained from



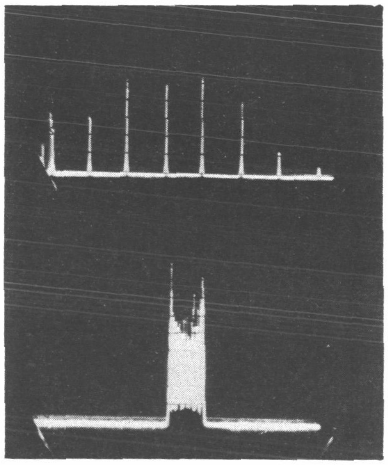
Peak-to-Peak Displacement = D
= 0.5 inches = 12.5 mm
Frequency = F = 1 Hz
Marker Spacing = MS = 0.25 MHz



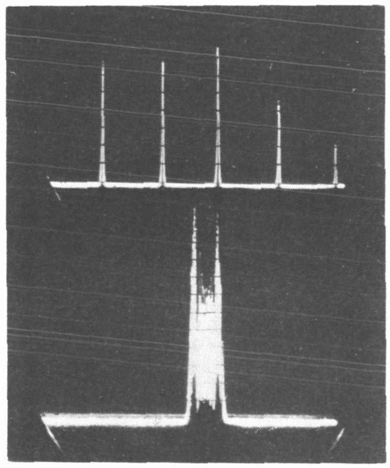
D = 1.5 mm
F = 10 Hz
MS = 0.25 MHz



D = 0.4 mm
F = 100 Hz
MS = 0.25 MHz

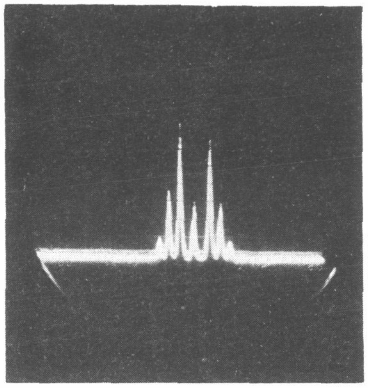


D = 5×10^{-3} mm
= 5 microns
F = 1000 Hz
MS = 0.1 MHz

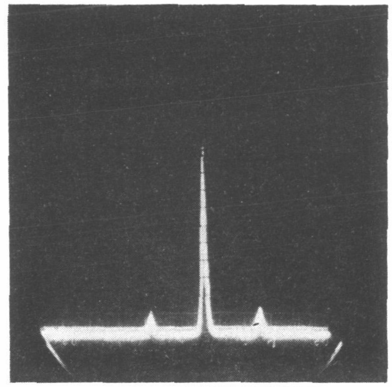


D = 1.3×10^{-3} mm
= 1.3 microns
F = 2000 Hz
MS = 0.1 MHz

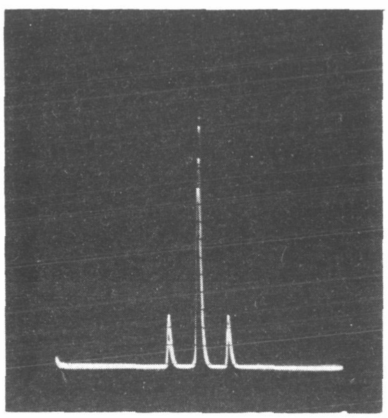
Figure 12. Vibration analyzer output spectra for various vibration amplitudes and frequencies. Frequency markers are top traces; output signals are lower traces.



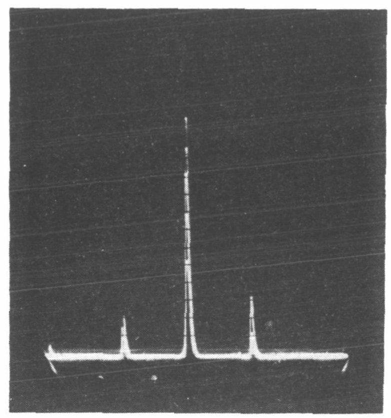
(a) Displacement = 2000 Å
Frequency = 10 kHz



(b) Displacement = 225Å
Frequency = 26 kHz



(c) Displacement = 500Å
Frequency = 250 kHz



(d) Displacement = 400Å
Frequency = 570 kHz

Figure 13. Vibration Analyzer output spectra for small displacements. Traces (a) and (b) were obtained with a loudspeaker voice coil to move the mirror. Traces (c) and (d) were obtained directly from the unpolished surface of a piezoelectric ceramic transducer.

a reference 25 MHz generator and calibrated attenuator. For the diffuse reflectors the signal fluctuates because of interference effects[2]. For some of the surfaces, data was taken both for normal incidence and 45° incidence. The instrument output polarization is essentially circular; thus no polarization orientation was recorded. The signal obtained from the internal reference or alignment mirror was also measured for comparative purposes. Results are given in Table I. Samples marked (*) were provided by NASA Ames Research Center. The flat white paint was lanthanum hydroxide in potassium silicate; the flat black paint is Parson's optical black laquer. The second surface aluminized sample was found to have a reflectance of only 57% for the laser light at near normal incidence; this explains the relatively low reading obtained for that sample. The diffuse white samples show maximum signals that are somewhat lower than anticipated. From geometrical considerations, one would expect the best signals to be greater than -42 dBm. (This discrepancy was also obtained using the breadboard optical system of the preceding program.) Beam depolarization and spreading in the microscopic surface structure must be responsible for the lower values. The sensitivity of the equipment is such that useful results may be obtained using the black painted surface, if the vibration amplitude is comparable to a wavelength or larger.

The results of the optical power measurements are indicated in Figure 14. From this data it is clear that about 74% of the available light for transmission can be collected from a perfect mirror through the relay optics and directional coupler. With a filter efficiency of 85%, this is an overall system power efficiency of 63%. This value is possible with so many components because of the efficiency of the dielectric coatings on the lenses and mirrors.

Table I.

Heterodyne Signal Power (0 dBm = 10^{-3} Watts)

Surface Material	Reflectance** (6328Å) %	0° Incidence		45° Incidence	
		Max	Min	Max	Min
Internal Reference Mirror		- 12 dBm	---	---	---
99.8% Dielectric Mirror		- 12 dBm	---	---	---
Second Surface Aluminized Mirror* (fused silica 6 mil substrate)	98.5	- 15 dBm	---	- 75 dBm	< - 90 dBm
Aluminum Foil Sample*	87.0	- 29 dBm	- 35 dBm	- 63 dBm	- 71 dBm
Flat White Paint Sample*	95.5	- 47 dBm	- 56 dBm	- 46 dBm	- 55 dBm
Flat Black Paint Sample*	1.0	- 62 dBm	- 72 dBm	- 60 dBm	- 67 dBm
Smooth White Paper		- 46 dBm	- 60 dBm	- 50 dBm	- 70 dBm
Scotchlite Tape		- 19 dBm	- 50 dBm	---	---

System Noise: - 91 dBm at 10 kHz bandwidth
- 93 dBm at 3 kHz bandwidth

*These samples were furnished by NASA-Ames Research Center.

**Measured with Beckman DK-1A Spectrophotometer and Gier-Dunkle AIS-6 Integrating Sphere.

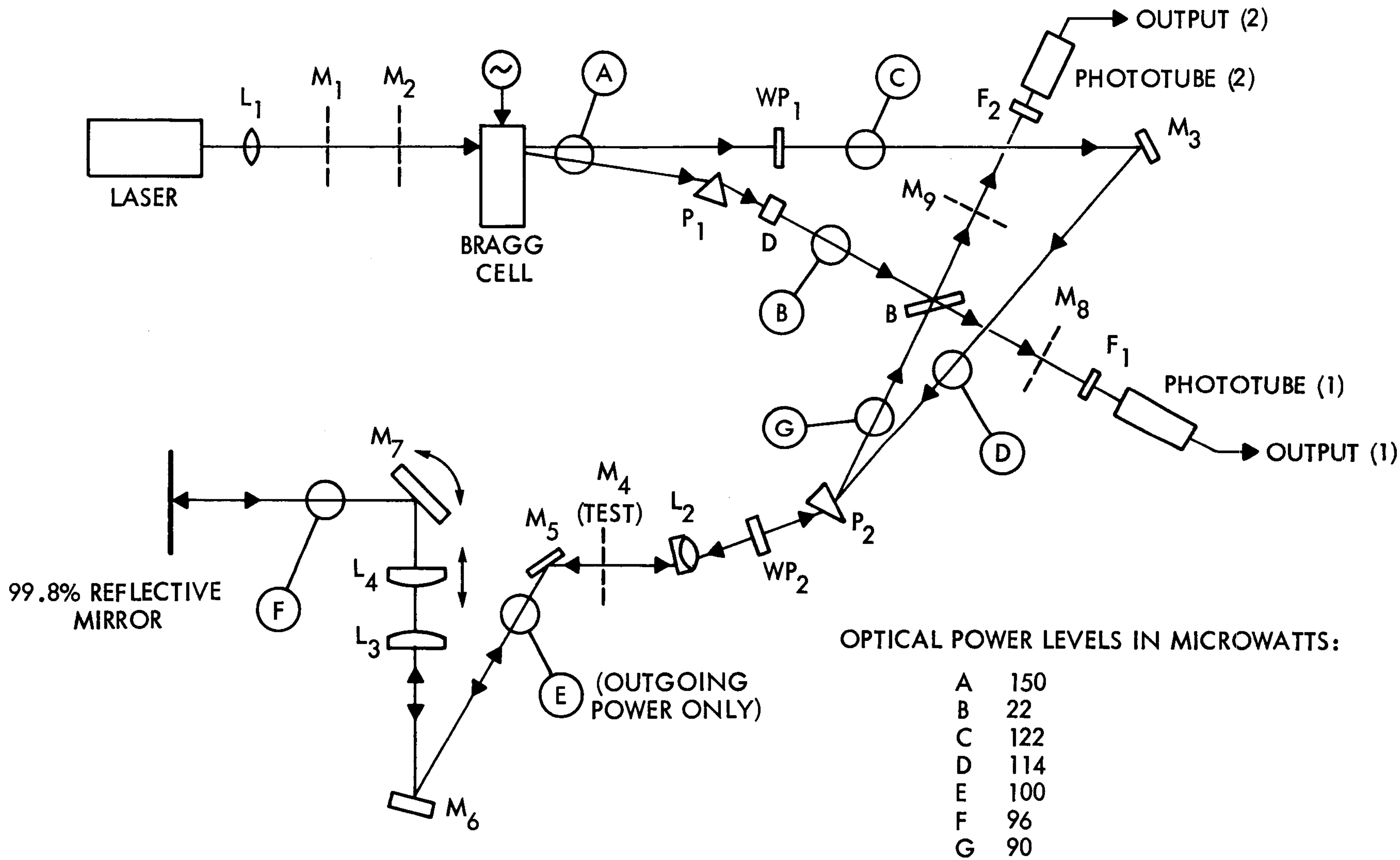


Figure 14. Laser Vibration Analyzer Optical System - Power Measurements.

REFERENCES

1. NASA CR 75643.

2. NASA CR 985.

3. M. Born and E. Wolf, "Principles of Optics," 2nd Edition (Pergamon) Macmillan, 1964, pp. 593-610.

4. F. E. Terman, "Electronic and Radio Engineering," 4th Edition, McGraw-Hill, 1955, p. 590, Ch. 17.

APPENDIX A

A.1 Operating Instructions

The instrument should be located in front of the vibrating surface with a distance of about three feet between the surface and the rectangular output window of the instrument. The wheels should be retracted before the test begins so that the instrument is securely located on the floor. The function switch on the laser power supply should be in the "on" position. If the unit has been plugged in and left in the standby position, no warm-up period for the laser is required. If power has been disconnected, a warm-up period as long as three hours for the laser oven may be required before the output power is fully stabilized; tests may be conducted sooner if the laser output is frequently adjusted by means of the manual "$\Delta\lambda$" control potentiometer on the laser power supply. In any case, the $\Delta\lambda$ control should be set initially for maximum laser output. This can be observed in several ways, the simplest of which is a crude visual adjustment for greatest apparent brightness of the output beam on the surface, followed by a final adjustment for maximum signal on the spectrum analyzer. The high voltage supply should be set with both the ac line and high voltage switches in the "on" positions. The voltage indicator dials should be set at 1100 volts and polarity should be negative. These settings should be left undisturbed to avoid the possibility of overvoltage at the phototubes. The oscillator B+ switch on the upper panel should also be turned on.

The output connection to the spectrum analyzer should be made using 50-ohm coaxial cable. A spectrum analyzer capable of displaying audio sidebands about the 25 MHz carrier should be used to display the signal. Equivalent noise at the spectrum analyzer input should be less than -90 dBm for a bandwidth adjusted to 10 kHz, if the full sensitivity of the optical heterodyne system is to be realized.

If the object has optically smooth surfaces, it will be necessary to orient the reflecting surface to be measured so that light returns to the optical system. This is easily done with room lights turned off, using a piece of white paper held beside the transmitted laser beam. When the returning signal is adjusted back into the optical system, it will move off the paper screen. Before performing this operation, it is necessary to check that the surface is near the focus of the transmitted beam. Final focusing adjustments are made with the crank handle on the side of the instrument after other settings have been made. It should be emphasized that the heterodyne receiver is very sensitive to focusing and the output signal will be very weak unless the object is within a few millimeters of the correct focus.

For diffuse surfaces, the orientation of the surface is not critical, but particular care must be taken in focusing because the signal is many dB weaker than for specular reflectors. Unlike the signal from specular objects, the signal from diffuse reflectors usually fluctuates in amplitude at low frequencies because of air currents and unavoidable bench vibrations. This is usually not a serious problem with vibration amplitudes of one micron or greater. However, for precise measurement at levels of 1000 Å or less, it is best to use rapid photographic exposures or rapid single-sweep displays of the analyzer to eliminate effects due to the fluctuations. Alternately, one can estimate time averages of the sideband heights in such cases.

With slight additional complication, one can also measure the parameters of the output with devices other than rf spectrum analyzers. By combining the system output signal and another tunable signal at a frequency f' in a mixer, as shown in Figure 15, the intermediate frequency carrier can be translated to any part of the spectrum. For precise measurements the difference between 25 MHz and f' might be set in the audio band, so that a scanning tunable voltmeter can be used to record the output. Alternately the difference (f' - 25 MHz) can be tuned to the input frequency of a commercial FM receiver. Such a receiver provides an output voltage proportional to surface velocity, at least for surfaces of relatively high reflectance and for vibration amplitudes that are not too large.

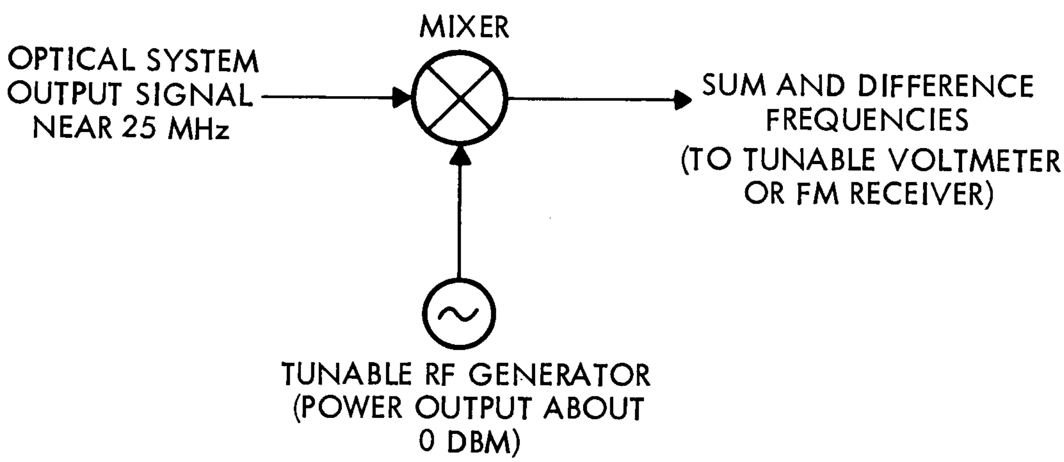


Figure 15. Alternate Processing Methods for Output Signal Display.

Interpretation of the spectra obtained using the spectrum analyzer or tunable voltmeter is discussed in Section 2 of this report. For vibration amplitudes <u>greater</u> than a few microns, the peak-to-peak excursion of the surface is given very accurately by the relation

$$2x_o = \frac{\lambda \Delta f}{4\pi f_v} \tag{1-A}$$

where $\lambda = 6328\text{Å}$, f_v is the known vibration frequency, and Δf is the measured total width of the spectrum. For double amplitudes <u>less</u> than one-tenth wavelength, it will usually be sufficient to use the approximation

$$2x_o \approx \frac{\lambda}{2\pi}\left(\frac{I_{SB}}{I_C}\right) = (0.10 \text{ microns}) \times \left(\frac{I_{SB}}{I_C}\right) \tag{2-A}$$

where I_{SB} is the current (or voltage) amplitude of the first sideband and I_C is the current (or voltage) amplitude of the carrier at 25 MHz. In terms of the powers in the carrier and sidebands, which are often measured more directly, the double amplitude is

$$2x_o \approx \frac{\lambda}{2\pi}\sqrt{\frac{P_{SB}}{P_C}} = (0.10 \text{ microns}) \times \sqrt{\frac{P_{SB}}{P_C}} \tag{3-A}$$

For amplitudes in the range between a few wavelengths and about one-tenth wavelength, there are no valid approximations, and one must use a table or plot of the Bessel functions of the first kind, up to the second or third order. The ratio of the currents or voltages in the carrier, proportional to

$$J_o\left(\frac{4\pi x_o}{\lambda}\right)$$

and in the first few sidebands, which are proportional to

$$J_n\left(\frac{4\pi x_o}{\lambda}\right) ; \; n = 1, 2, 3 \ldots$$

will be measured and compared to values in a table[2] of these functions. This will quickly indicate the correct value for $4\pi x_o/\lambda$, from which $2x_o$ is easily computed.

Observation of the shape of the spectrum will immediately indicate which of the above cases is valid. With the sweep speed of the analyzer set at a slow rate, the first case (large amplitudes) is characterized by a spectrum of many sidebands, perhaps so dense that the sidebands are unresolved. For the second case (very small amplitudes) there will be only two sidebands of any appreciable amplitude, one on either side of the carrier, and the sidebands will be considerably weaker than the carrier. For the third case there will be substantial power in several sidebands, but the number of significant sidebands will be less than about ten. The accuracy of the approximation used in the first case is indicated, in a given instance, by the rate at which the sidebands at the extremes of the observed spectrum drop from large values to insignificant values as a function of frequency. This uncertainity in the precise "edge" of the Doppler spectrum is a measure of the error in this approximation. The error in the second case can be estimated by considering the magnitude of the third order term in the Taylor's series expansion of $J_1(y)$:

$$J_1(y) = \frac{y}{2} - \frac{y^3}{16} + \frac{y^5}{384} - \frac{y^7}{18,432} + \cdots \tag{4-A}$$

where $y = 4\pi x_o/\lambda$ in the present case. The approximation assumes that only the first order term above is significant. In the third case above, no approximation is used, and accuracy is limited only by noise and by the degree of accuracy one desires in interpolating the arguments of the functions from the mathematical table or graph.

A.2 Instrument Maintenance

The prototype instrument has been designed to require a minimum of maintenance. In an instrument employing such a complex and precise optical system, there are a great number of mechanical adjustments which must be properly made for efficient operation. These have been securely fastened down during assembly and testing of the instrument, and it is not anticipated that they will be changed. However, due to vibration in transport, etc., a few components may require occasional realignment.

The laser power may be adjusted by rotating the "$\Delta\lambda$" potentiometer on the laser power supply to obtain maximum light output. Other adjustments require the removal of the sheet metal top cover.

The most sensitive adjustment in the optical system is the beamsplitter mirror angular alignment. This is set by movement of two knurled brass thumbscrews located on the beamsplitter mounting block. The adjustment is made using a spectrum analyzer as a receiver and the internal test mirror M_4 (see Figure 3) as the reflecting surface. First the test mirror is rotated into the upright position; in this position the mirror block is spring-loaded against three locating points and should resist motion in any direction. With the laser, oscillator B+, and phototube voltage turned on, the 25 MHz beat tone produced by the light reflected by the test mirror is observed on the spectrum analyzer. Careful adjustment of the thumbscrews on the beamsplitter mounting fixture is then carried out to achieve the maximum possible signal at 25 MHz. The expected absolute signal power achieved in this way should be in the range of -10 dBm to -20 dBm. This adjustment should be carried out with the instrument wheels retracted, since variations in stress in the frame can affect the optical deck casting and might otherwise produce an incorrect alignment.

The water in the Bragg cell is sealed by a phenolic and rubber pressure cap on top of the device. If the water is to be removed for any reason, the cap may be lifted off and the rf connector to the oscillator removed. The cell is removed from the deck by removing two screws from each of the aluminum bars which clamp the cell in position on the steel rods at the base of the device. Care should be taken since the crystal quartz transducer in the end of the tank is backed only by air on the outside and will not support large internal pressures. Only distilled water should be used in the tank.

There are two additional precautions to be taken with regard to the Bragg cell and oscillator. First, the <u>rf power should never be applied to the cell when the tank is empty or when air bubbles are present on the transducer face</u>. Dry operation is likely to shatter the crystal and the resulting impedance mismatch may result in damage to the rf oscillator. Secondly, the oscillator B+ should never be turned on when the connection to the Bragg cell has been removed, since the oscillator should never operate into an impedance other than 50 ohms. The gain control circuit in the oscillator is sensitive to VSWR and can cause excessive current to be drawn if a strong reflected wave is present.

In time the laser tube will lose power and require replacement by the manufacturer. The laser is removed from the system by unscrewing the louvered side panels. The platform on which the laser, lens L_1, and mirror M_1 are mounted is then removed by carefully unscrewing the three 1/4-20 Allen head screws which attach the platform to the six-inch stand-off rods. The laser assembly may be lowered and removed by supporting the platform from below as the screws are loosened. The cables to the laser supply are disconnected by rotating the connector shells on the back of the supply. The central sheet metal air baffle must also be loosened in order to free the cables so that the laser assembly can be separated from the instrument. Removal of the laser for tube replacement generally requires readjustment of mirrors M_1 and M_2 as well as readjustment of the Bragg cell for maximum diffracted energy into the local oscillator beam. The adjustment of M_1 is such that the laser beam strikes M_2 near the center of the mirror. The adjustment of M_2, which must be made very accurately, is made to position the transmitted beam at the correct off-axis location on the outer side of lens L_2. This position should be noted before the laser is removed. Location of the spot on L_2 to within about 1/2 millimeter is all that is required, but the long optical path from M_2 and L_2 makes the angular adjustment of M_2 very critical. After all these adjustments are made, the beamsplitter must also be realigned by the procedure described above.

The optical surfaces of all components except the calcite prism can be cleaned by careful swabbing with lens tissue saturated with acetone. The coating on the calcite crystal is extremely fragile and should only be cleaned with compressed air or by very light brushing with a soft, clean brush. Special dust covers are provided for both prisms; they should not require cleaning under ordinary circumstances.

APPENDIX B

Definition of Symbols

$i(t)$ = photocathode current with signal and local oscillator beams incident.

I_{LO} = photocathode current with only the local oscillator beam incident.

I_S = photocathode current with only the signal beam incident.

$\omega = 2\pi f$ = angular frequency of the system intermediate frequency shift (radians/second).

ϕ_S = phase of the signal beam.

ϕ_{LO} = phase of the local oscillator beam.

x_o = peak displacement of the vibrating surface.

$(x_o)_{min}$ = minimum measurable value of x_o.

λ = laser wavelength (6328Å in this case).

$\omega_v = 2\pi f_v$ = angular vibration frequency (radians/second).

i_{ac} = alternating component of the photocurrent.

$J_n(\delta)$ = Bessel function of δ, first kind, nth order.

I_1 = photocurrent amplitude at the first order sidebands.

i_n = alternating noise (r.m.s.) component in the photocathode current.

e = electronic charge = 1.6×10^{-19} coulombs.

B = circuit bandwidth for which i_n is defined.

Δf = approximate total spectral width of the phase modulation produced by the vibrating surface.

S/N = signal-to-noise power ratio.

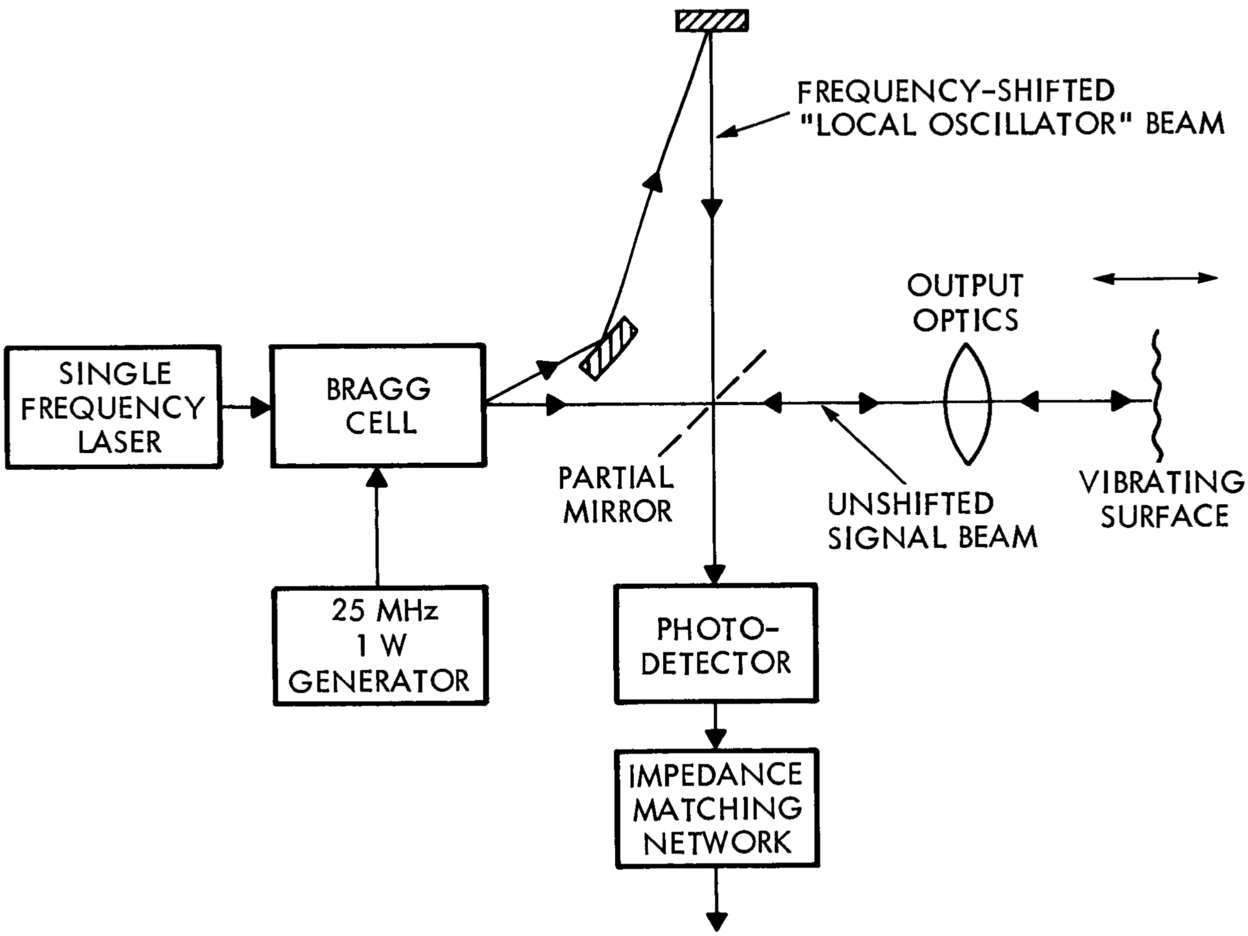
All equations are consistent with MKS units.

National Aeronautics and Space Administration

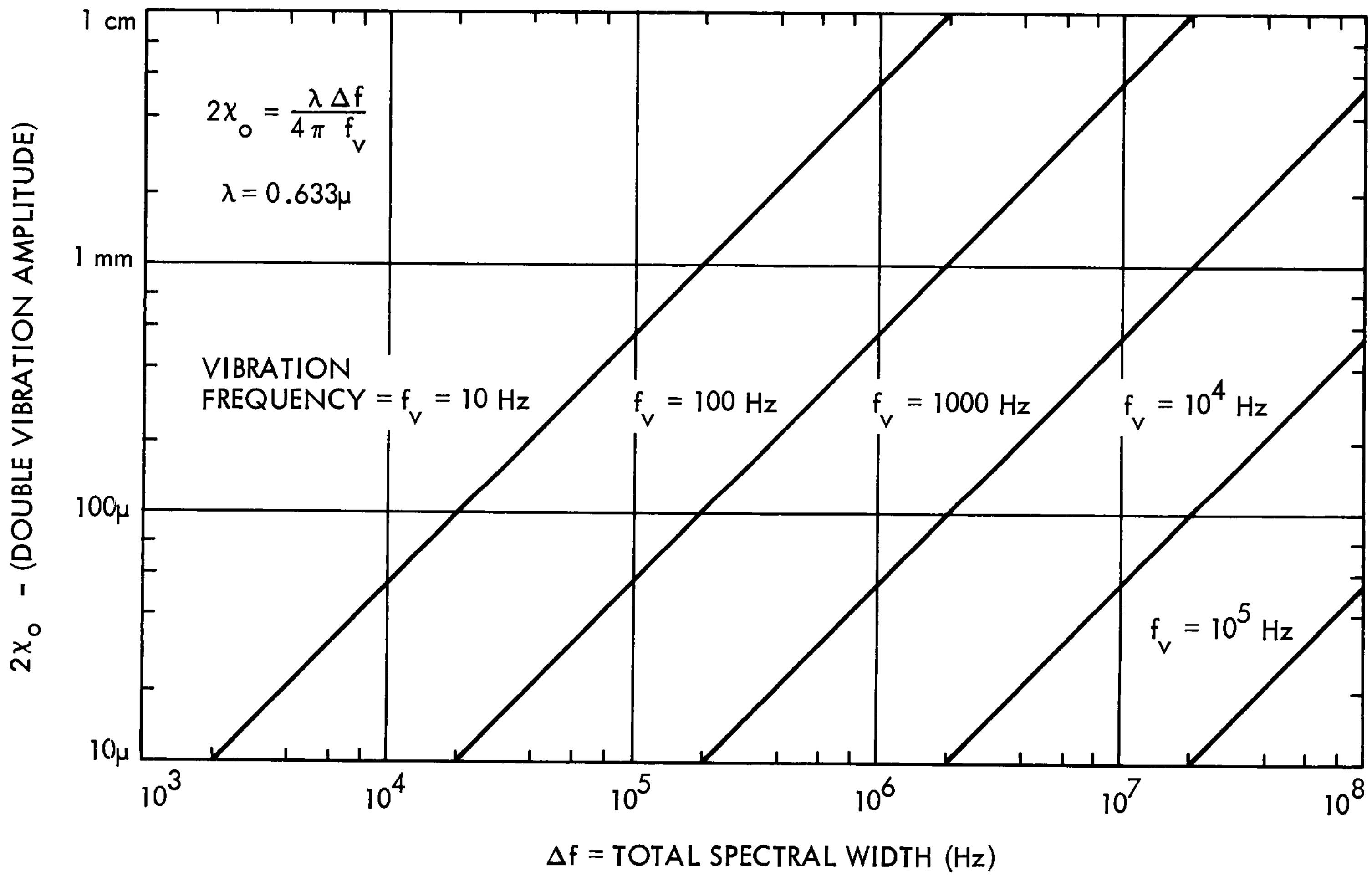
LASER VIBRATION ANALYZER

Gail A. Massey. December 1967.

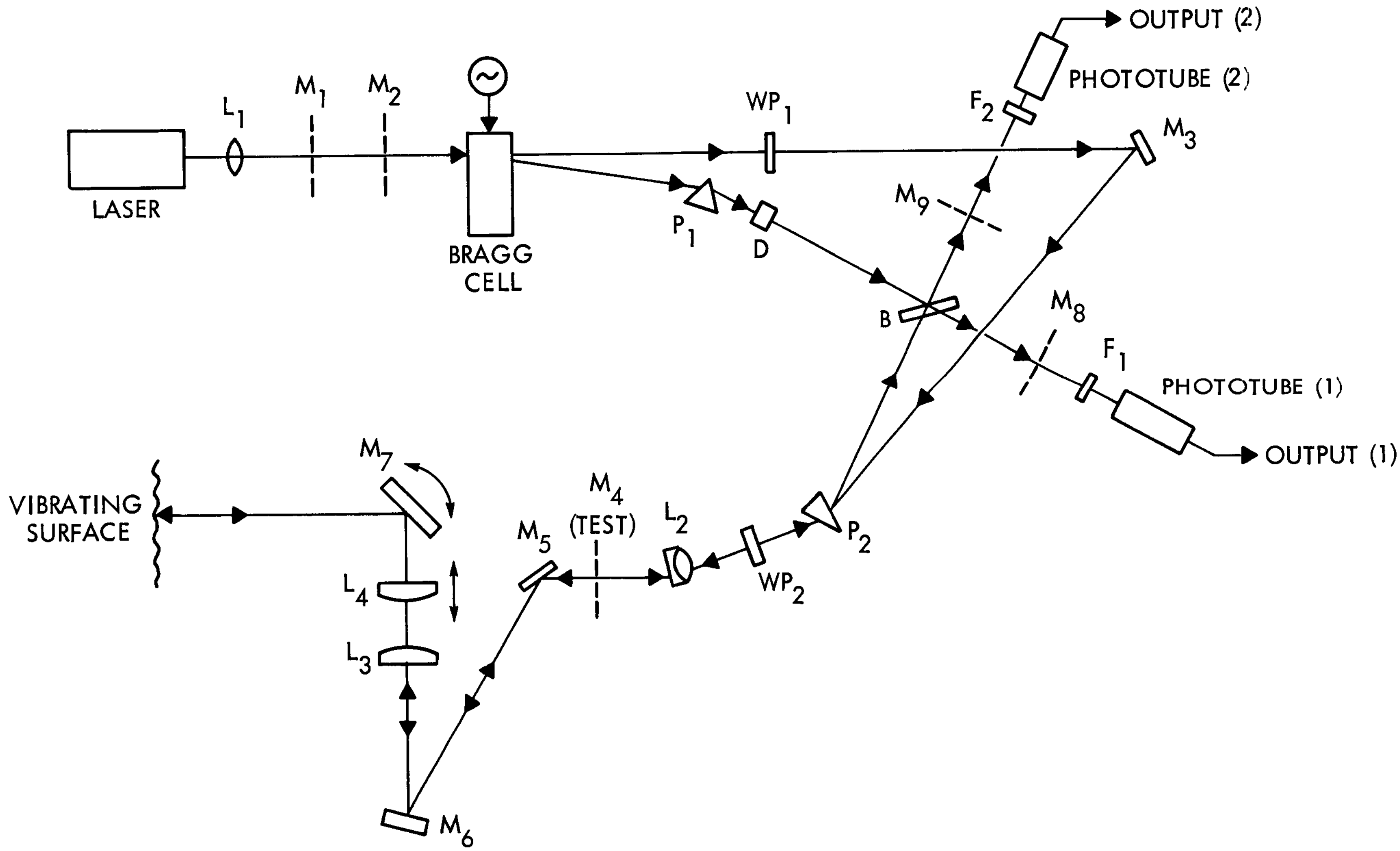
This report describes a development program for the purpose of designing, fabricating, and testing a prototype laser vibration measuring instrument. During two previous study efforts, the optical heterodyne technique was selected as the most promising method for remote measurement of vibrations over a wide range of amplitudes and frequencies. The prototype instrument is designed to operate at a distance of three feet from the vibrating surface. The output beam is focused on the surface and can be scanned manually by means of a rotatable steering mirror. The output of the device is a frequency-modulated signal centered at 25 MHz; the phase shift of this signal is proportional to surface displacement. Vibration frequencies from 1 Hz to 0.5 MHz have been measured with this instrument, with displacements from 1/2 inch peak-to-peak down to approximately 10^{-4} microns. The surface may be specular or diffusely reflecting. This instrument is designed for use with a spectrum analyzer as the display device; however, means for operating the laser vibration analyzer with a tunable voltmeter or FM receiver for signal demodulation and recording are also described.



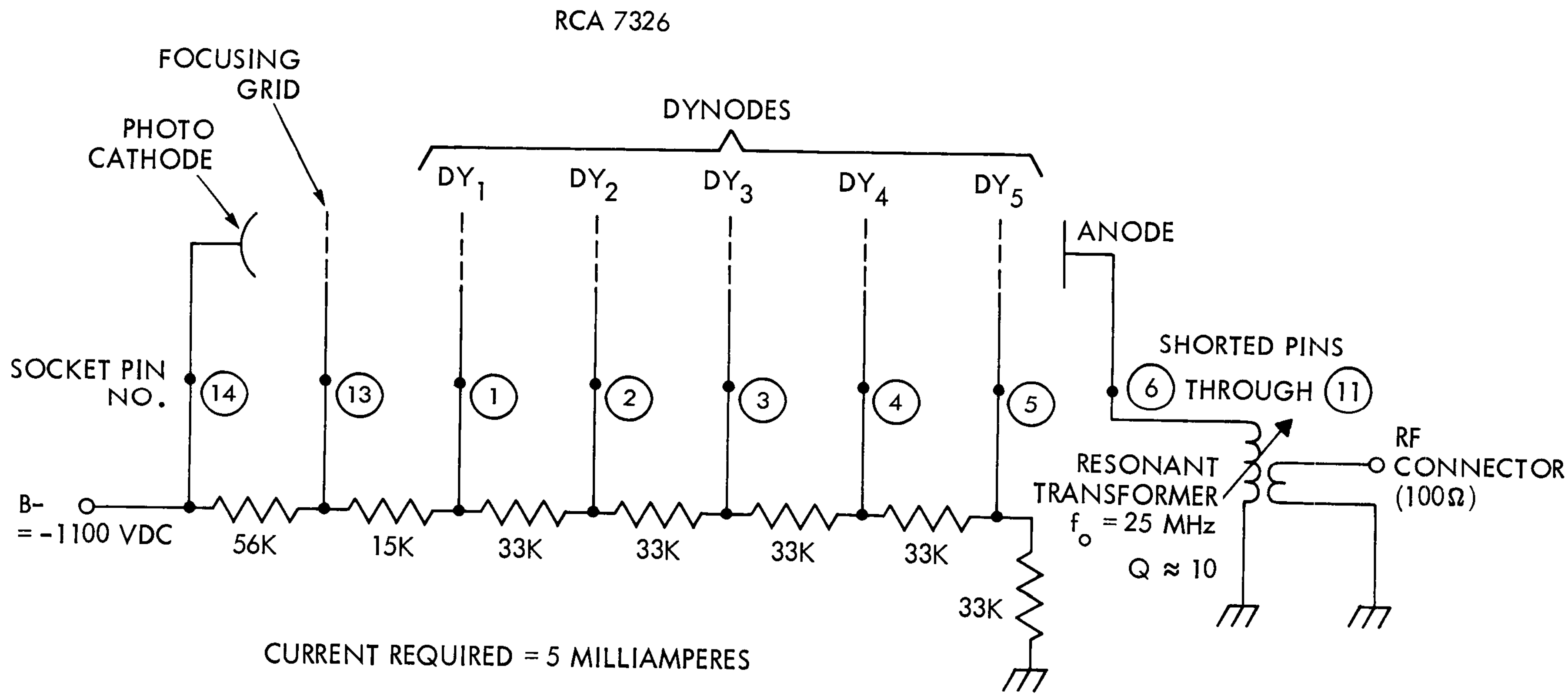
FREQUENCY-SHIFTED
"LOCAL OSCILLATOR" BEAM
OUTPUT
OPTICS
SINGLE
FREQUENCY
LASER
BRAGG
CELL
PARTIAL
MIRROR
UNSHIFTED
SIGNAL BEAM
VIBRATING
SURFACE
25 MHz
1 W
GENERATOR
PHOTO-
DETECTOR
IMPEDANCE
MATCHING
NETWORK
OUTPUT TO SPECTRUM ANALYZER
(INTERMEDIATE FREQUENCY SIGNAL
NEAR 25 MHz)



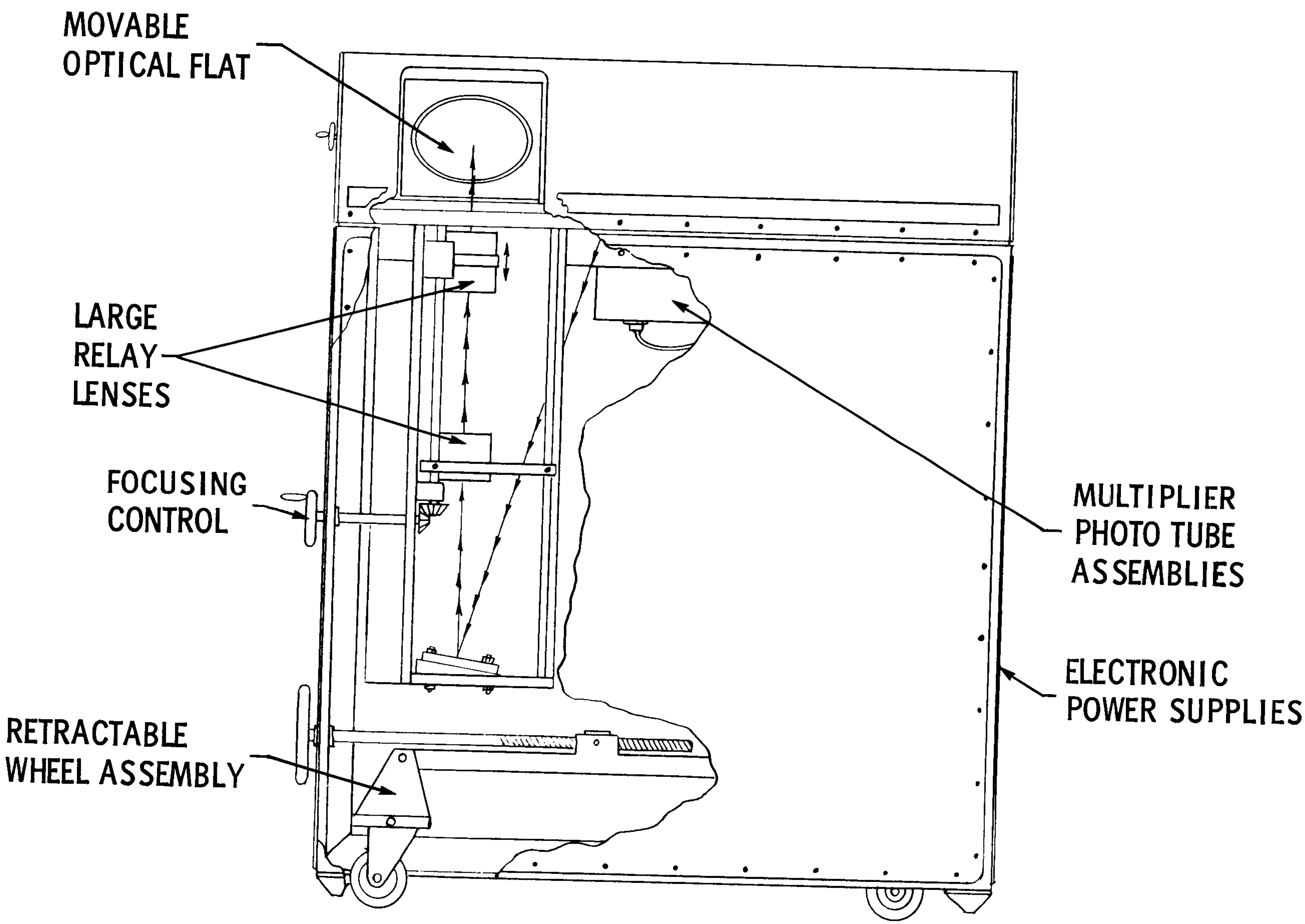
1 cm
1 mm
100μ
10μ
2χ_o - (DOUBLE VIBRATION AMPLITUDE)
2χ_o = λΔf / 4π f_v
λ = 0.633μ
VIBRATION FREQUENCY = f_v = 10 Hz
f_v = 100 Hz
f_v = 1000 Hz
f_v = 10^4 Hz
f_v = 10^5 Hz
10^3
10^4
10^5
10^6
10^7
10^8
Δf = TOTAL SPECTRAL WIDTH (Hz)

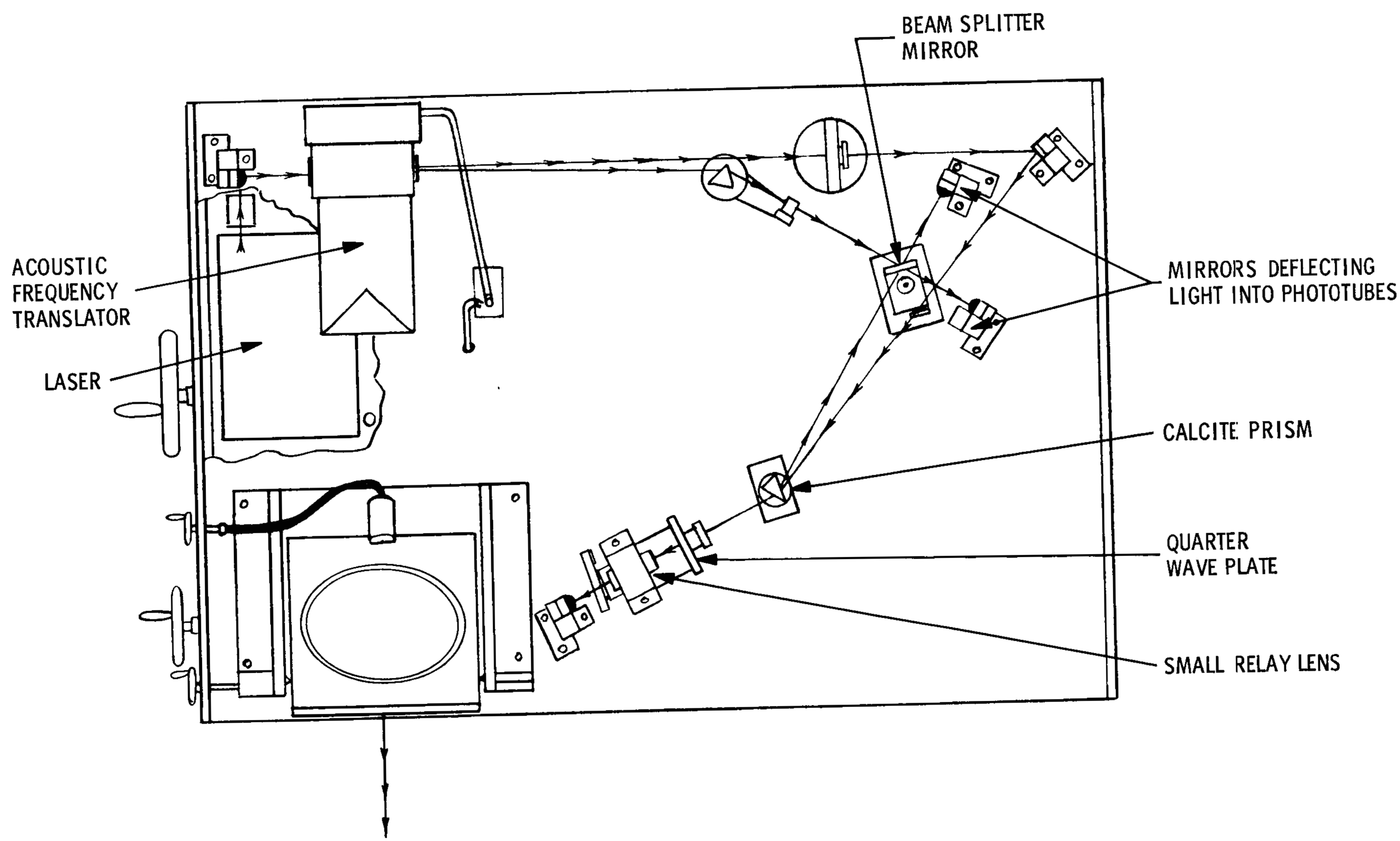


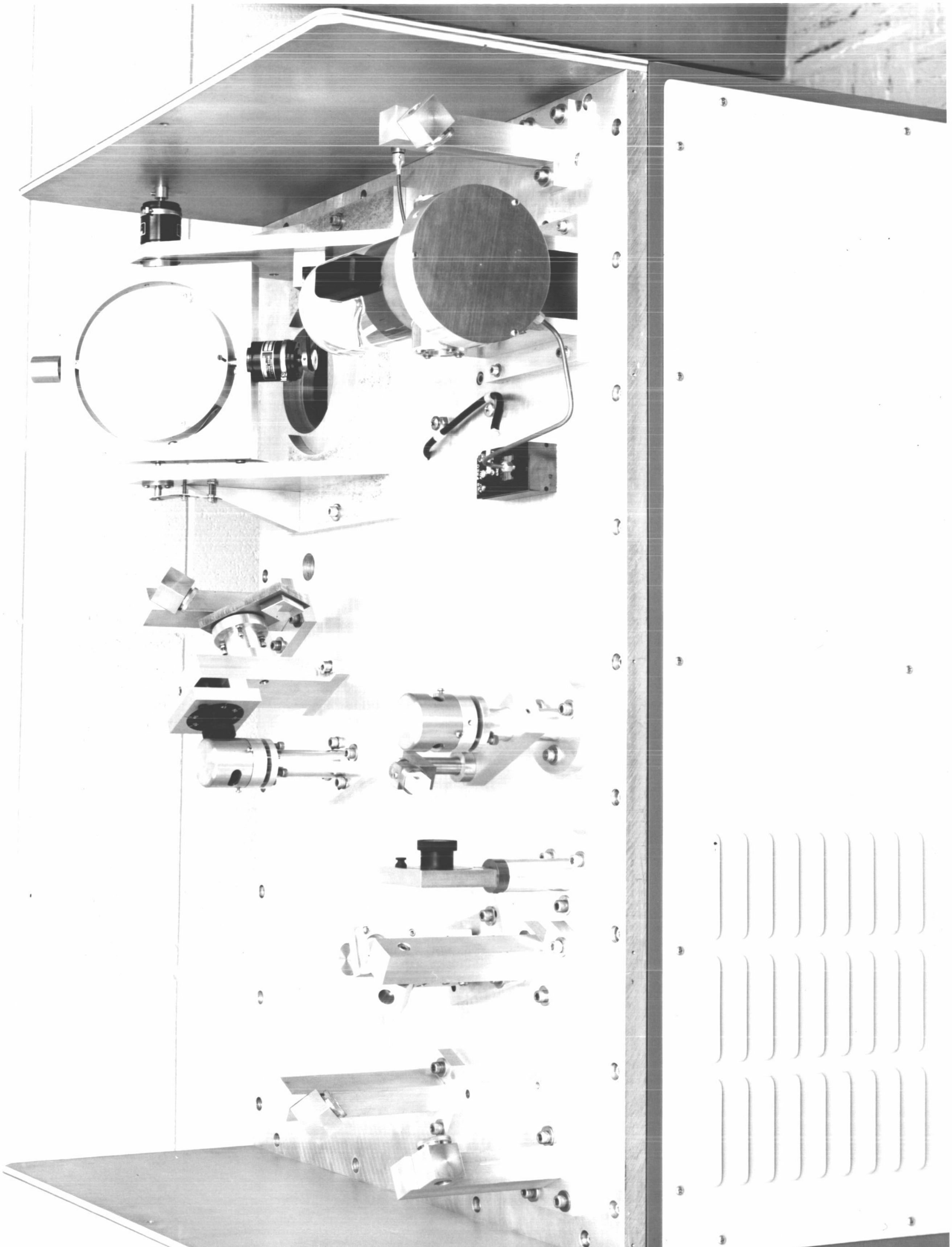
LASER
L_1
M_1
M_2
BRAGG CELL
WP_1
P_1
D
B
M_3
M_9
F_2
PHOTOTUBE (2)
OUTPUT (2)
M_8
F_1
PHOTOTUBE (1)
OUTPUT (1)
P_2
WP_2
L_2
M_4 (TEST)
M_5
M_6
L_3
L_4
M_7
VIBRATING SURFACE



RCA 7326
FOCUSING GRID
PHOTO CATHODE
DYNODES
DY1
DY2
DY3
DY4
DY5
ANODE
SOCKET PIN NO.
14
13
1
2
3
4
5
SHORTED PINS
6 THROUGH 11
RF CONNECTOR (100Ω)
RESONANT TRANSFORMER
fo = 25 MHz
Q ≈ 10
B- = -1100 VDC
56K
15K
33K
33K
33K
33K
33K
CURRENT REQUIRED = 5 MILLIAMPERES


MOVABLE OPTICAL FLAT
LARGE RELAY LENSES
FOCUSING CONTROL
RETRACTABLE WHEEL ASSEMBLY
MULTIPLIER PHOTO TUBE ASSEMBLIES
ELECTRONIC POWER SUPPLIES

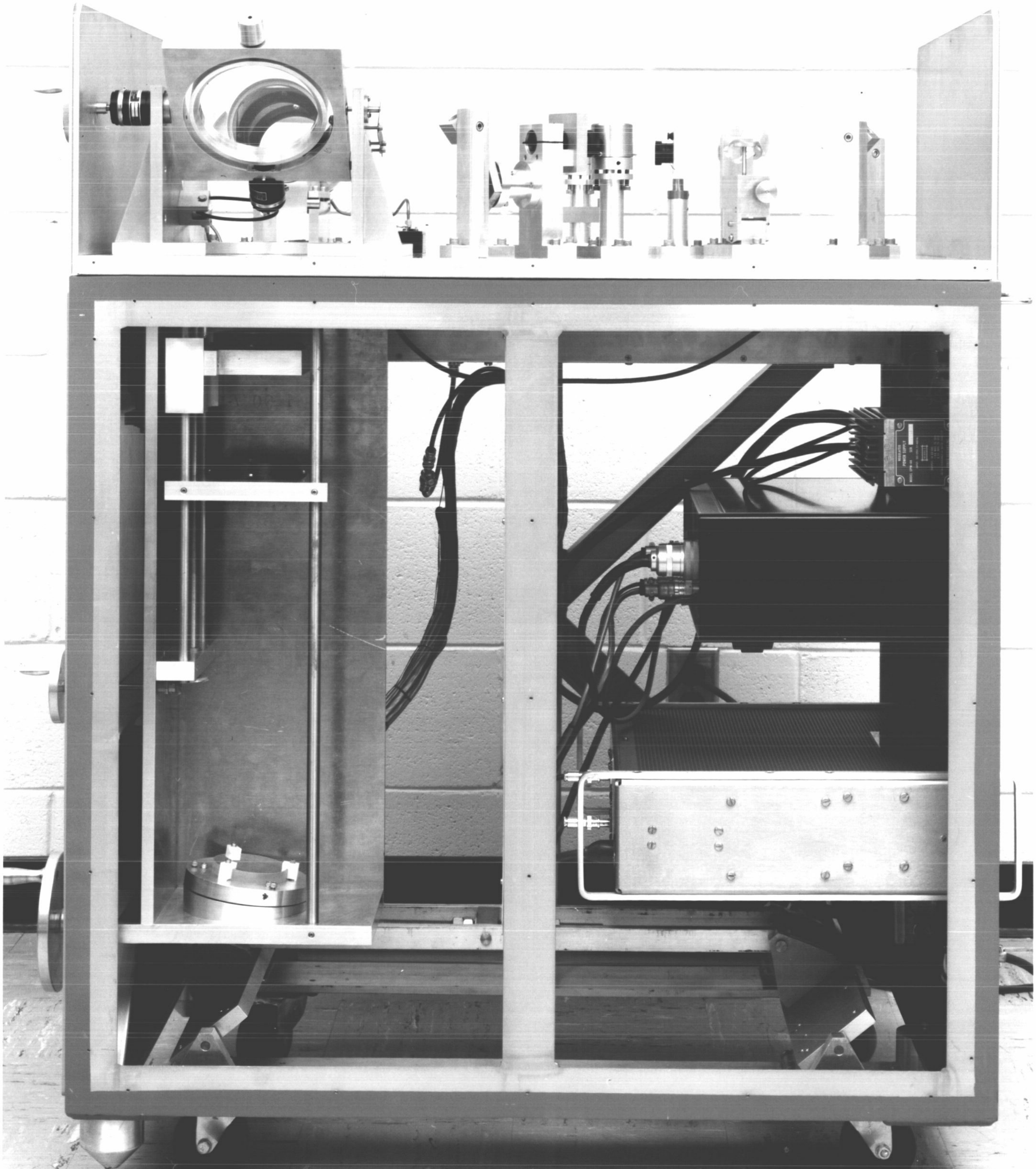

BEAM SPLITTER MIRROR
MIRRORS DEFLECTING LIGHT INTO PHOTOTUBES
ACOUSTIC FREQUENCY TRANSLATOR
LASER
CALCITE PRISM
QUARTER WAVE PLATE
SMALL RELAY LENS



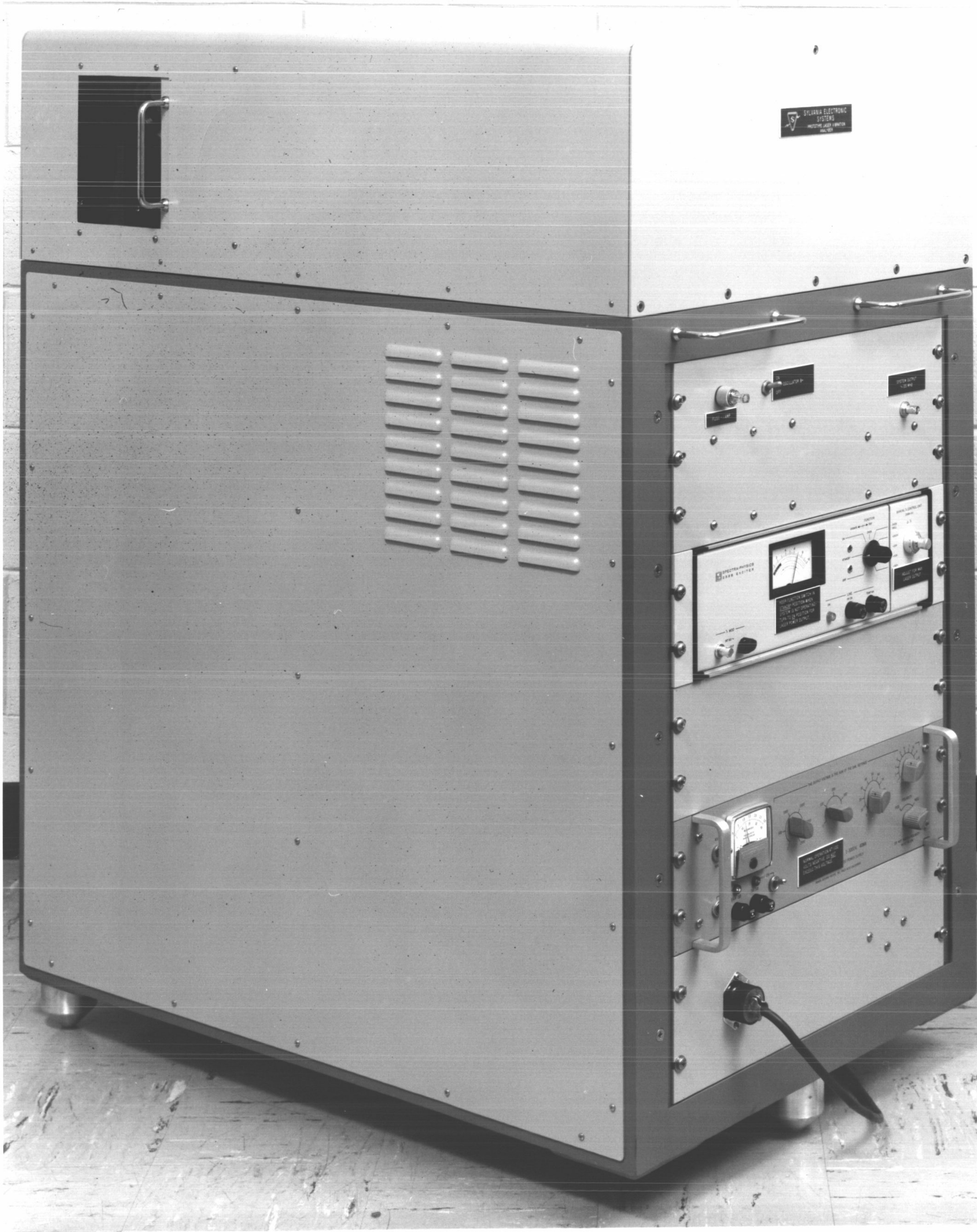
6/11/2703

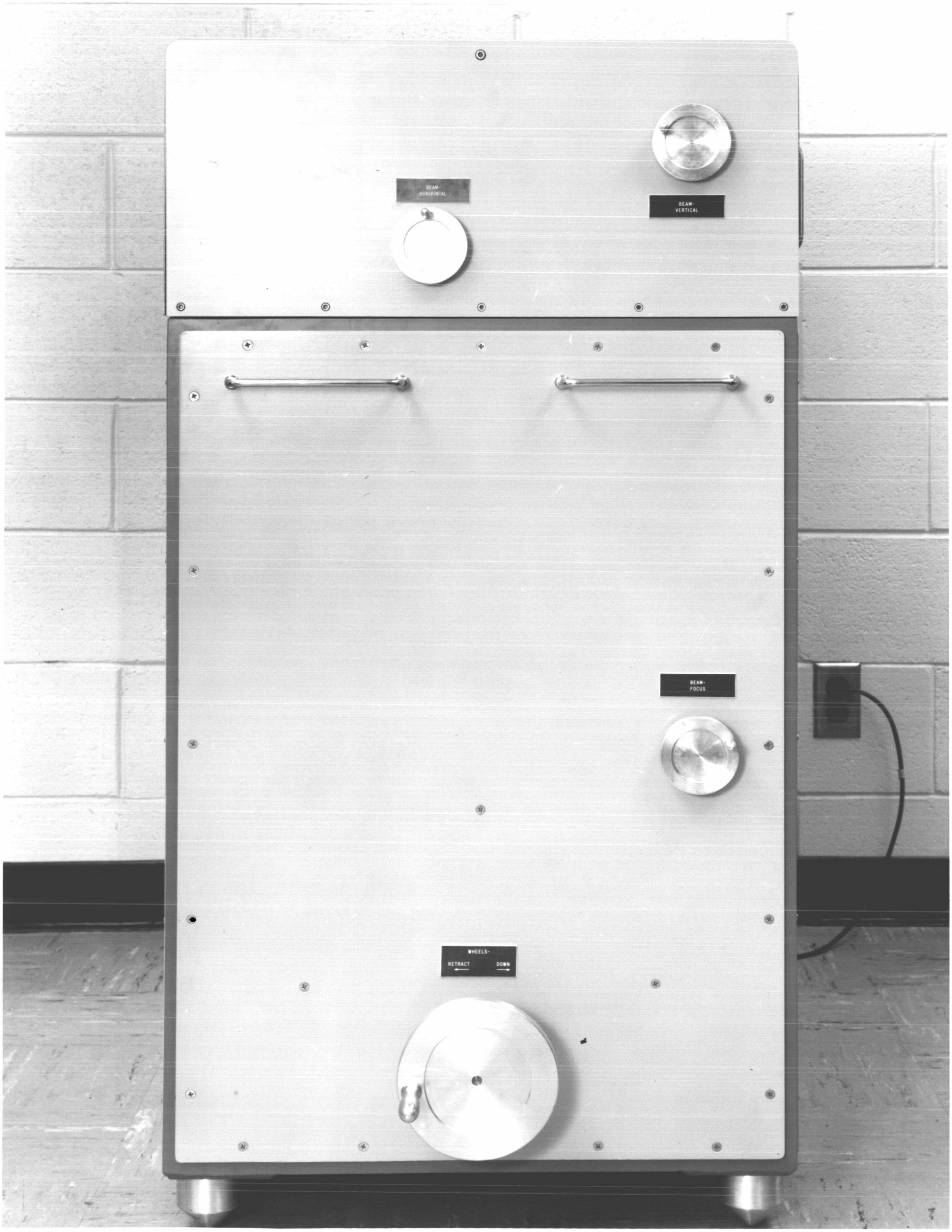
X

105



35


SYLVANIA ELECTRONIC
SYSTEMS
PROTOTYPE LASER VIBRATION
ANALYZER


BEAM-
HORIZONTAL
BEAM-
VERTICAL
BEAM-
FOCUS
WHEELS-
RETRACT
DOWN

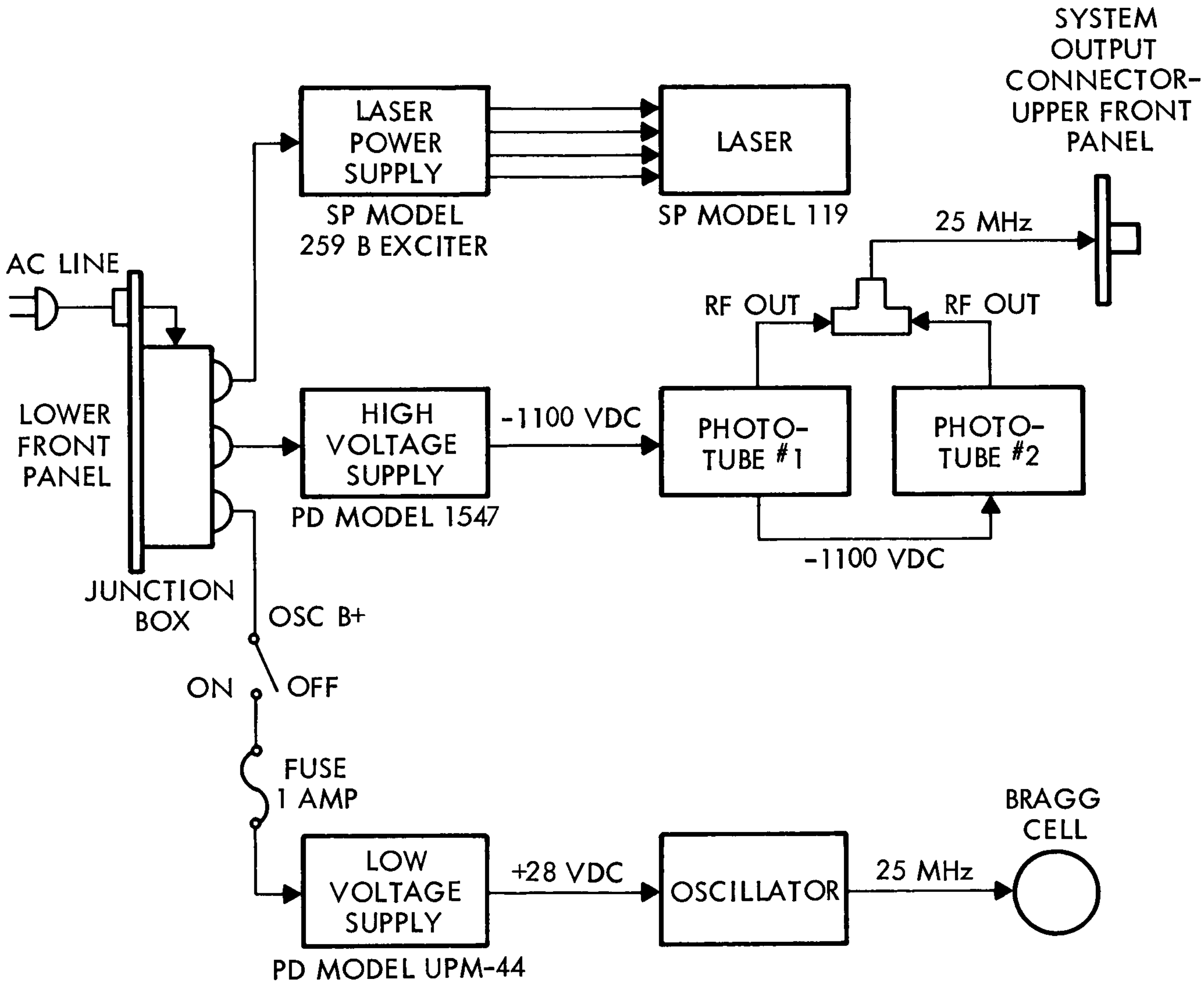
6 7/21409

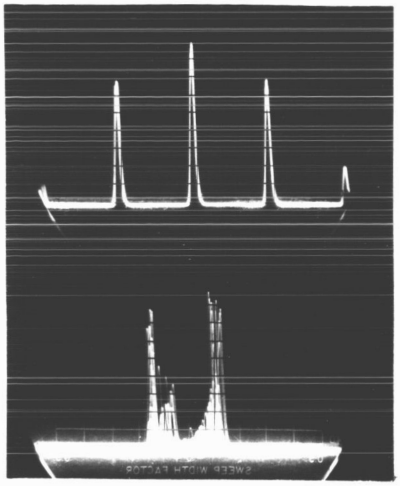
862

35

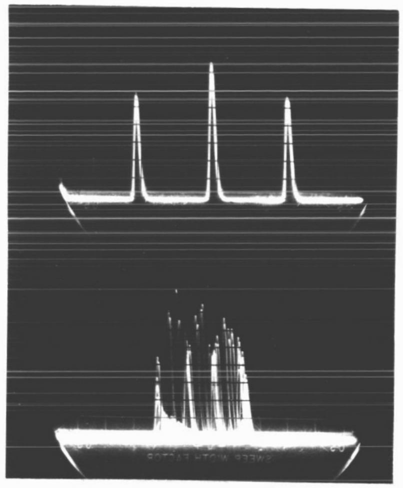
SYL...

... VIEW, CALIF.

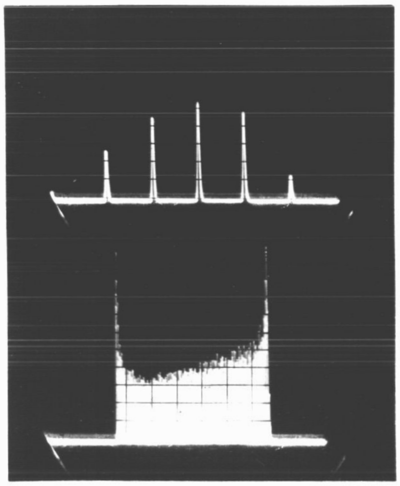

SYSTEM OUTPUT CONNECTOR-UPPER FRONT PANEL
LASER POWER SUPPLY
SP MODEL 259 B EXCITER
LASER
SP MODEL 119
25 MHz
AC LINE
RF OUT
RF OUT
LOWER FRONT PANEL
HIGH VOLTAGE SUPPLY
-1100 VDC
PHOTO-TUBE #1
PHOTO-TUBE #2
PD MODEL 1547
-1100 VDC
JUNCTION BOX
OSC B+
ON
OFF
FUSE 1 AMP
BRAGG CELL
LOW VOLTAGE SUPPLY
+28 VDC
OSCILLATOR
25 MHz
PD MODEL UPM-44



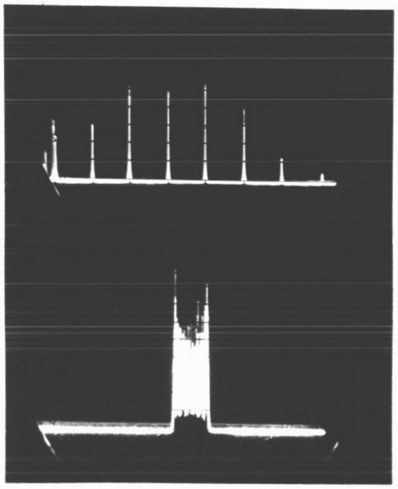
Peak-to-Peak Displacement = D
= 0.5 inches = 12.5 mm
Frequency = F = 1 Hz
Marker Spacing = MS = 0.25 MHz



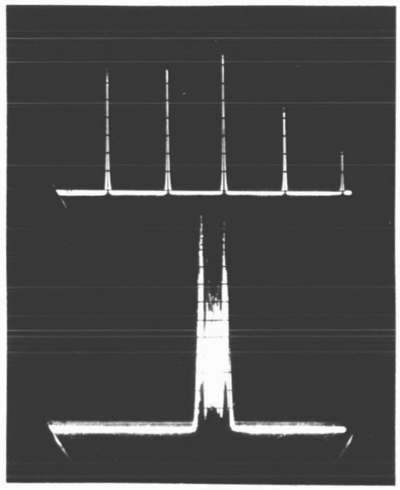
D = 1.5 mm
F = 10 Hz
MS = 0.25 MHz



D = 0.4 mm
F = 100 Hz
MS = 0.25 MHz

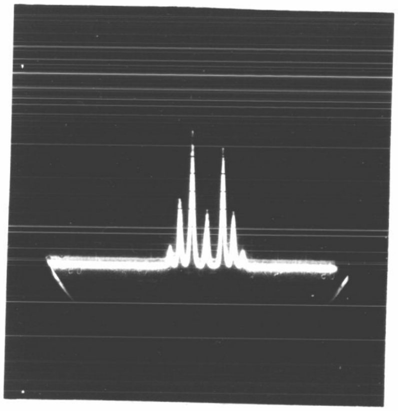


D = 5×10^{-3} mm
= 5 microns
F = 1000 Hz
MS = 0.1 MHz

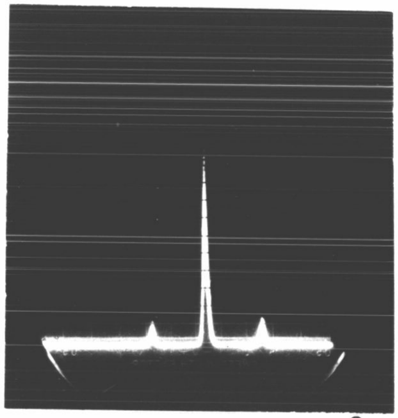


D = 1.3×10^{-3} mm
= 1.3 microns
F = 2000 Hz
MS = 0.1 MHz

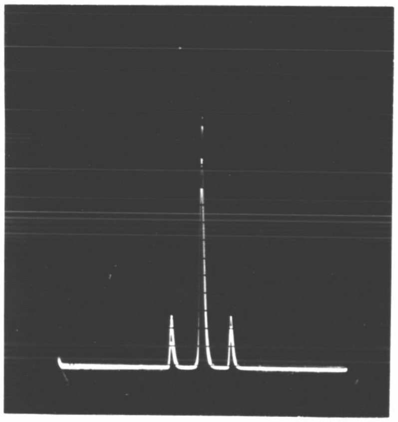
Figure 12. Vibration analyzer output spectra for various vibration amplitudes and frequencies. Frequency markers are top traces; output signals are lower traces.



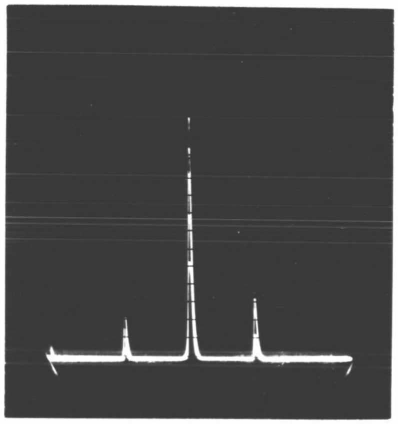
(a) Displacement = 2000 Å
Frequency = 10 kHz



(b) Displacement = 225Å
Frequency = 26 kHz

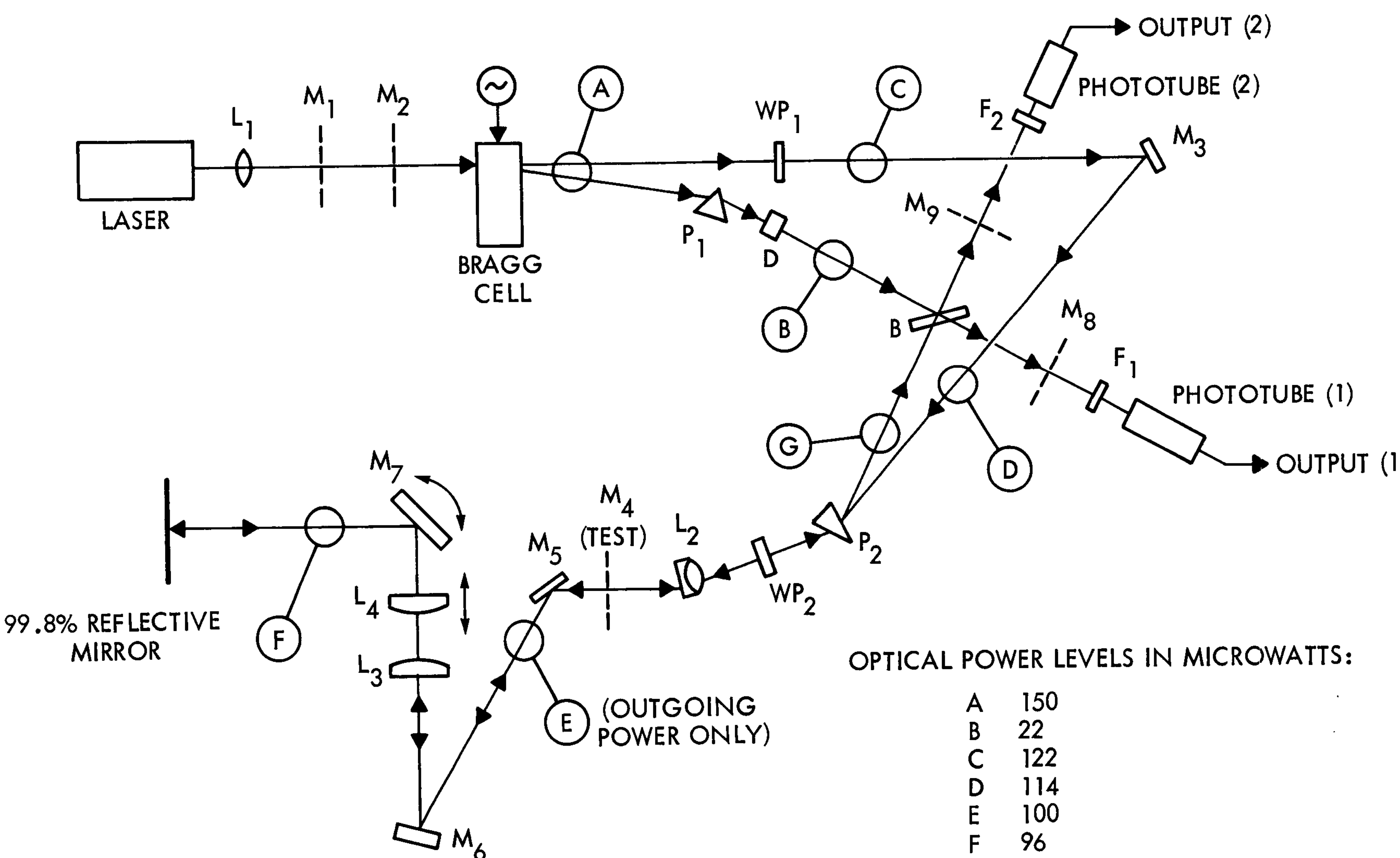


(c) Displacement = 500Å
Frequency = 250 kHz



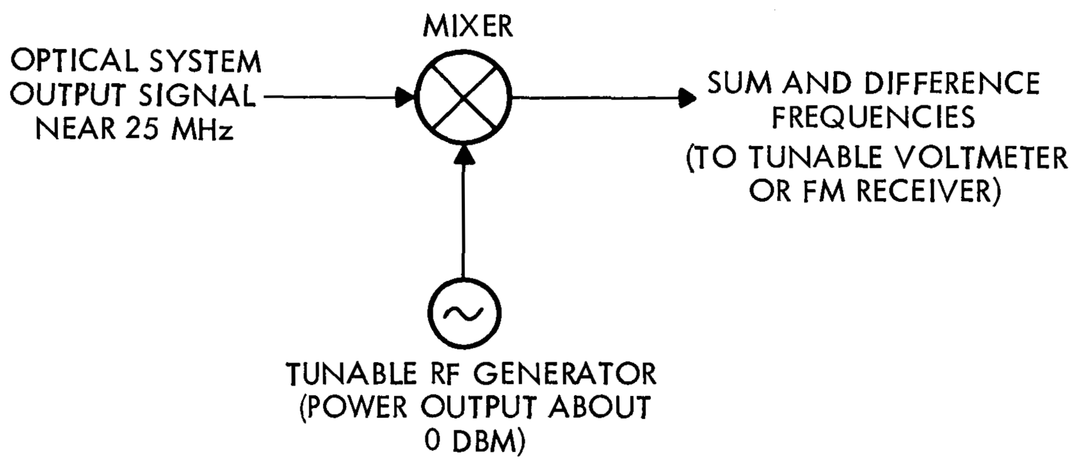
(d) Displacement = 400Å
Frequency = 570 kHz

Figure 13. Vibration Analyzer output spectra for small displacements. Traces (a) and (b) were obtained with a loudspeaker voice coil to move the mirror. Traces (c) and (d) were obtained directly from the unpolished surface of a piezoelectric ceramic transducer.



OPTICAL POWER LEVELS IN MICROWATTS:

A	150
B	22
C	122
D	114
E	100
F	96
G	90


MIXER
OPTICAL SYSTEM
OUTPUT SIGNAL
NEAR 25 MHz
SUM AND DIFFERENCE
FREQUENCIES
(TO TUNABLE VOLTMETER
OR FM RECEIVER)
TUNABLE RF GENERATOR
(POWER OUTPUT ABOUT
0 DBM)